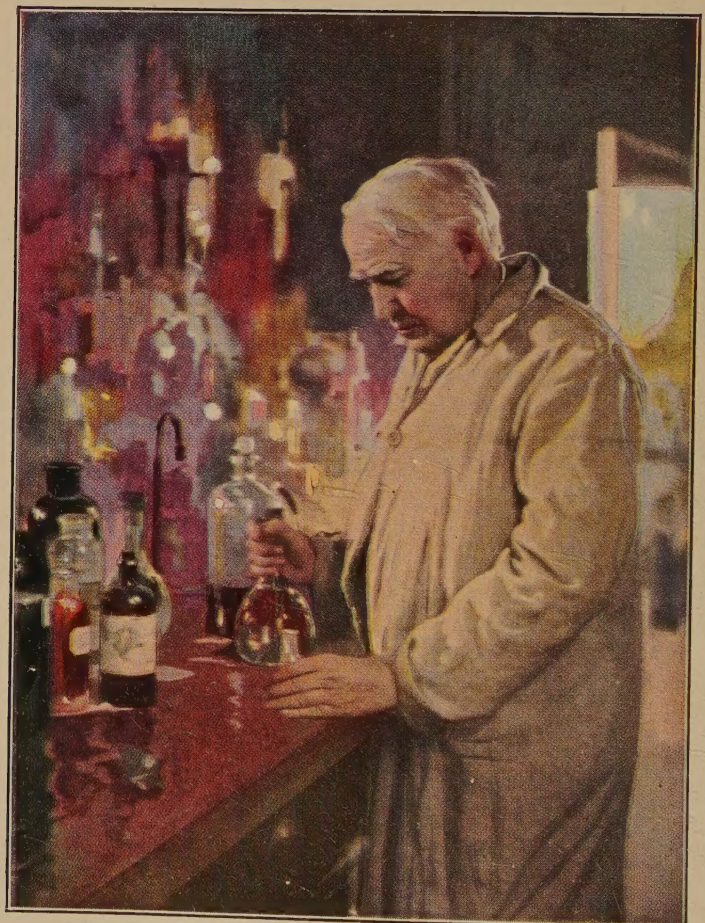

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Thomas Alva Edison in His Laboratory

ARRANGED IN SIXTEEN VOLUMES
WITH A HISTORY OF SCIENCE, GLOSSARIES
AND A GENERAL INDEX

SUPPLEMENTED BY A LOOSE-LEAF VOLUME EMBODYING
THE MOST IMPORTANT DEVELOPMENTS IN SCIENCE,
ANNUALLY, FROM 1923 TO 1932

ILLUSTRATED

VOLUME SEVEN

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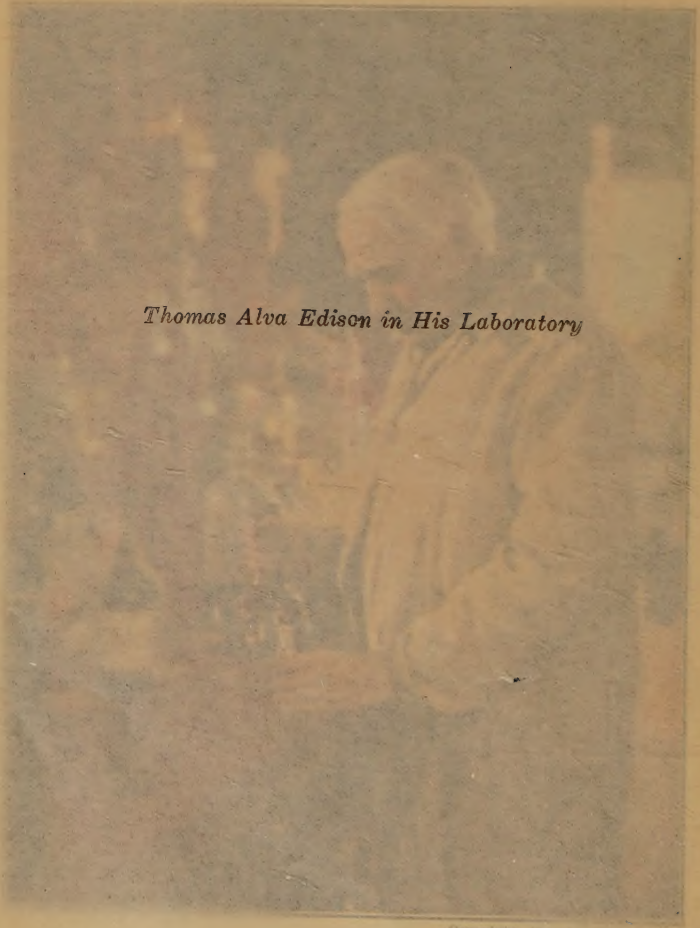

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ELECTRICITY AND MAGNETISM

The Science of Power

BY

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IN TWO VOLUMES

II. APPLICATIONS

P. F. COLLIER & SON COMPANY
NEW YORK

PREFACE

THE Science of Electricity is advancing so rapidly and is finding so many new applications each day, that any record thereof will always seem incomplete. The authors have aimed, however, for the present volume to select from the many groups of applications those that are typical.

Although a consistent effort has been made to explain the theories and principles involved in each case, limited space has often made it necessary to refer the reader to the first volume on Electricity for a more exhaustive treatment thereof.

In a sense, then, each chapter of this volume is complete in itself. If a knowledge of the many and varied economic electric devices available for the home is desired, the chapter on Electrical Applications in the Home ought to supply it. These devices may, at least in name, not be entirely new to the reader, but it is hoped that the explanation of the principles concerned will help toward a clearer conception of their operation and toward a greater enjoyment thereof.

The same is true of the chapter on "Electricity on the Farm." This will show that the mysterious force Electricity can be intelligently applied to practically every operation now entailing hand labor.

The important subject of Illumination is one that should receive special attention. The constant and extensive demand upon our eyes in reading and in doing exacting work, makes it advisable to have a

knowledge of the art of Illumination in order that we can conserve our energy by applying it to the best advantage.

The chapter on Telegraphy and Telephony and Radio covers the latest applications of electricity to this remarkably interesting field.

No phase of man's life can long remain unaffected by Electricity. In overcoming sickness as well as in promoting health, it is daily finding additional applications. The new interpretation of electricity as described in the chapter on the Electron Theory (in volume VI) has promoted an intelligent advance in the art of Electro-Therapy.

Diagrams and plates have again been introduced throughout this volume to illustrate the written matter. Care has been exercised in selecting and designing such cuts and diagrams that exactly interpret the text. In many instances complex illustrations have been taken and properly simplified and thereby made more interesting and helpful. Through this pictorial method the reader will be able hereafter to identify many machines and devices which he may have seen frequently, but whose application he did not know.

The glossary which completes the volume contains a review of the important laws, principles, theories, as well as of the specific and general terms and words used throughout both volumes. It will be found serviceable as a source of reference and as a guide in reading.

Through this review, then, of the theory and the practice of Electricity goes the sincere wish of the writers that the readers and the students may be helped to a better grasp and a greater use of one of the foremost forces known to man.

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CHAPTER I

TRANSMISSION OF ELECTRICAL ENERGY

AN important division of the profession of electrical engineering is the transmission of electrical energy from the large power houses to the thousands of customers in the surrounding territory. This transmission has grown to such an extent that at present hardly a town, village or city of fair size cannot be supplied with adequate electrical equipment and power. The extensive transmission facilities now available have, further, brought the current from the power house more cheaply and more efficiently than it could be supplied by the small private plants.

Perhaps the reader has already formed a picture or opinion of such a transmission system. He may regard it simply as two, three, or more wires hung upon a series of poles placed at regular intervals from one place to another. Unfortunately, the transmission engineer who designs and constructs these systems does not find his problem so easy of solution. No one else feels more keenly the fact that electricity cannot be carried a greater distance than is possible at present. Wonderful advance, however, in the long-distance transmission of electrical energy has been made within the past decade; but there are still many limitations to be overcome. The transformer engineers of the great

manufacturing plants assure us that they are in a position to design and construct transforming apparatus up to and even beyond 500,000 volts for commercial application should such a demand be made. At present the highest long-distance transmission system in use employs a voltage of only 150,000 volts. This seems very high indeed, but until still higher voltages can be impressed upon a system, unless some other radical improvement now unknown can be devised, the highest possible distance of transmission will be confined to a radius of about two hundred miles or over.

A system is now under construction in southern California where a voltage of 225,000 volts will be employed and from the results of the 150,000-volt system satisfactory results are anticipated. This system will be of assistance in the solution of the general problem as it will afford basic material for further improvements. The reader will probably wonder why so much care becomes necessary in increasing the voltage of a new system, only a small amount above the highest value then in practice. It seems that when such high voltages become impressed upon a system which, as heretofore stated, is always three phase for long distance, the electric strain between the wires and the ground becomes so great that the air soon reaches such a highly charged state that it becomes partially conductive and leaks electricity away from the wires. This leakage if witnessed in the dark is accompanied by a beautiful violet glow about the wire and also by a characteristic sound as of the soughing of a wind through a forest. This effect is called *corona discharge.* Sometimes the term *brush discharge* is also applied. It is always

present on high-voltage systems where the strain of the atmosphere surrounding the wires approaches a certain critical value. This value depends upon many factors, such as the size of the wire, the altitude above sea level, the condition of the atmosphere, the magnitude of the voltage and the like. On the 150,000-volt line now in operation, the engineers in charge did not attempt to eliminate the corona loss in the system, but actually allowed for the existence of a certain amount. They found that little if any harm is done by the discharge and that the loss sustained is less than would be the expense involved in trying to obviate it, or than would be the loss entailed by shortening the length of line and thereby losing certain patronage.

This long-distance, high-voltage, pole line construction is by no means, however, the only type of construction, and neither is it necessarily of the greatest importance. Another type of considerable prominence is the underground transmission system by means of tunnels and conduits. This system is used principally in large towns and cities where it would be impracticable and inadvisable to permit the multitude of wires, cables, and complications of network involved in transmission work, to be placed on poles in the streets. Not only would life be in constant danger from accidental contact by breakage, but the appearance of such a system would be most unsightly. City ordinances, therefore, have restricted the use of overhead wires in up-to-date communities to the single wires associated with trolley systems. Even these are occasionally in certain trolley systems placed underground, where contact is secured with the under part of the car through slots constructed midway between the rails.

This underground type of transmission of power, however, presents its own problems, and ingenuity must be exercised and much experimentation be performed in order to give the satisfactory results expected by the customers, as well as by the engineers of the utilities. Frequently the energy has to be transmitted rather long distances, as in New York City and Chicago, where the city covers a large territorial space for the relatively low voltage permitted by the local regulations. Usually twelve thousand to fifteen thousand volts marks the upper limit for the voltage of such systems, although a few systems do permit a voltage of twenty-five thousand. The wires are run through vitrified ducts made of a certain type of clay and baked with a glazed surface. Since this construction gives little or no opportunity for ventilation, care must be exercised not to overload the cables and thereby destroy the insulation and, possibly in the time of greatest need, to cause a disastrous breakdown of the entire system.

These underground cables are constructed in a manner radically different from that of the overhead system. In the construction now most extensively used one polarity wire for a two-wire cable is made up of several strands of smaller wire for the core. This is surrounded with a thorough insulation of rubber preparation and jute. Over this are placed the strands that constitute the other polarity wire, which is also carefully insulated and treated to expel all moisture and then covered with a lead sheath or pipe. The wire is next waterproofed and is further protected against any ordinary mechanical injury. In this completed form, since it has been made of strands, it may readily be subjected to bends and twists without the injury attendant

upon solid wire. This type of construction is called the *concentric cable.* There are, however, cables made where the two conductors are thoroughly insulated from each other and are also lead-covered. These are called the *duplex cable.* For three-phase work three such stranded conductors are made within a single lead covering.

Figure 135 shows a view of a section of vitrified duct. The ducts are laid in continuous connection from block to block, opening only into the manholes

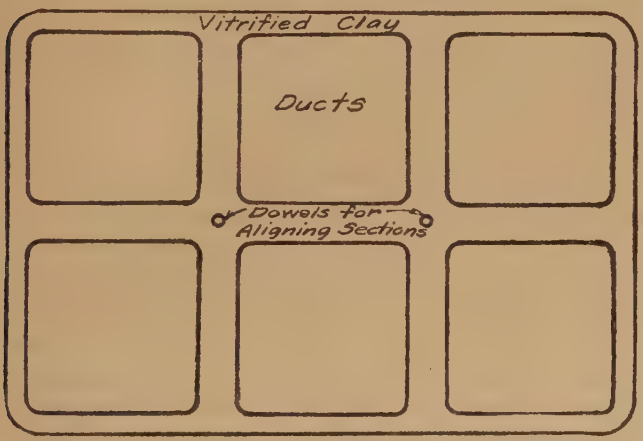


FIG. 135.—VITRIFIED CLAY CONDUITS FOR UNDERGROUND TRANSMISSION

where branches and feeders may be joined in order to tie together the lines of the entire system. By this means a better voltage regulation is maintained throughout the system.

To show how dangerous it is to overload machinery and equipment, consider the following illustration of underground transmission. On a certain evening about eight o'clock, one of the cables

in a duct, located in one of the busiest electrical localities of New York City, collapsed because of excessive heat resulting from a continued overload. A violent explosion accompanied the collapse and led to the melting and breaking of the duct. In addition the remaining cables broke down one after the other in a similar manner until over forty cables had been ruined and a large territory in the Thirty-fourth Street section had been rendered inoperative. Over one thousand men were called into service and were at the repairs in less than three hours, and before seven o'clock the next morning the large customers were again supplied with energy through temporary wires laid directly in the street. Following this disaster, immediate investigation was begun to test the condition of the system and to forestall any further similar disaster. It was found to be quite generally true that the cables were overloaded and subjected to excessive temperatures because of the lack of radiation.

Now that we have fundamental information of the general problem at hand and of the importance thereof, let us take up each system separately and discuss its characteristic features. First, let us consider the overhead system called the *pole-line type*. The cheaper systems as well as the short lines are usually constructed on wooden poles, but the more important and more permanent systems are constructed on steel towers reenforced by latticed bars and guy rods, which give additional strength. The wires are held by insulators mounted on cross arms near the top. Everyone has probably seen in the streets near the curbs wooden poles with cross arms for holding the insulators. These cross arms that carry the wires are supported by iron

braces. The three wires of a three-phase system, however, are more usually supported by the insulators located at the vertices of either an equilateral or a right-angle triangle. This construction gives the best result in transmission. Insulators may be supported upon pins, and in this case called *pin-type insulators*. These are often employed to as high

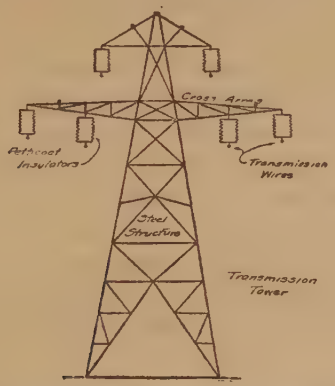


FIG. 136.—STEEL TRANSMISSION TOWER WITH HIGH-TENSION INSULATORS CARRYING TWO THREE-PHASE SYSTEMS

a voltage as 50,000 volts; but for higher voltages it is not advisable to mount the insulators in this way, since the pins must be made too large for convenient attachment and the stresses then become excessive. For higher values of voltage, the *suspension type of insulators* may be used. These may be seen by referring to Figure 136, which shows a steel tower. The suspension type insulator is made so that many of the skirts or petticoats, as they are called, may be placed together to provide insulation for as high a voltage as the system requires. The reason for making the skirts of the

inverted saucer shape and for mounting them one over the other is to make the creepage distance from the wire to the pin, which may be grounded, as great as possible, and thereby give to such a path a very high resistance. Accumulation of dirt and moisture reduces this surface or creepage resistance and if an arc once starts along some such path, the insulation will quickly become ruined.

Pole-line construction is especially open to and subjected to the dangers from high induced voltages and surges of electrical energy in the live wires that would damage almost any insulator regardless of how careful its construction and materials. These surges of current are like the violent agitation of the water in a bathtub which occurs when one lifts his body out suddenly, and thereby causes the splashing or slapping over of the water. They rush back and forth in the system with great speed often amounting to several hundred thousand or possibly millions of times in a second, and set up great strains in the insulators, and may break down the insulation of the transformers and sometimes ruin the dynamos and other equipment. Further, they are often set up by lightning discharges in the vicinity of the wires. As a precaution, therefore, a method similar to that found in the safety valve of a boiler should be established to relieve the strain when it increases above normal. Such devices have been constructed and installed with considerable success. Their action may be shown best by considering Figure 137. These high-frequency surges have great opposition offered to them by even a very small inductance, but the opposition offered by this inductance to a sixty-cycle current would

amount to practically nothing. Therefore the coils "L" and "L," called *choke coils*, offer very high resistances to these high frequency surges, and if placed in the lines just as they enter the power house would successfully impede the impulse from entering the building and damaging the machinery therein contained—provided always that a means

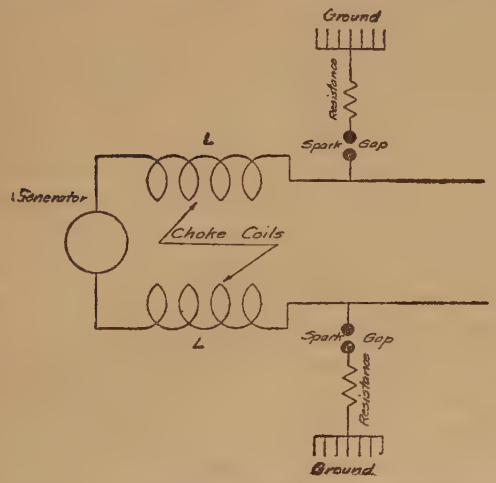


FIG. 137.—CHOKE COILS WITH LIGHTNING ARRESTERS FOR DISCHARGE TO GROUND

of escape is permitted for this great stress. Lightning arresters serve to accomplish this by permitting a path for this current to flow to the earth. There are various types of arresters, but the most commonly used is called the *aluminum arrester*. If this were connected directly to the line, there would be a continuous leakage of electricity to the ground. In order to eliminate this a gap, called a *horn gap*, is placed between the line and the arrester and the earth. This gap, which is shaped like a pair of

horns, serves another purpose. As soon as the abnormal stress is relieved by the arcking across of the horn gap to ground, the arc should go out and not permit the normal line energy itself to dissipate itself in maintaining this arc. The arc, by virtue of its tremendous heat, sets up immediately a strong draught which blows the arc up on the prongs of the horn and thereby causes it to break. The normal voltage of the system is insufficient to reestablish this arc. Therefore, any abnormal discharge may break down the horn gap and cause the current to pass through the aluminum arrester and to ground. The aluminum cups of the arrester are immersed in a solution of aluminum hydroxide. As the current flows through the cell a film of hydroxide forms upon the cups and increases its resistance until the united action of this increased resistance and the lengthening arc of the horn gap puts out the arc and prevents the normal line voltage from sustaining the flow of current. Not only will such destructive surges be established by the discharge of a bank of clouds, by a lightning flash, or other atmospheric phenomena, but likewise by the sudden opening of a line switch on a long transmission line or by the throwing of a large motor or other load suddenly upon the line.

A successful method of relieving the stresses that are set up by the static attraction of the clouds with the wires, and which when suddenly released by a stroke of lightning causes the surges, is to run an *earth wire* along the pole tops and to connect it to the ground every pole or two. The charge is grounded then as fast as it collects and thereby eliminates much of the possible danger that would otherwise occur. Thus, the grounded wire acts, in

severe lightning storms, to protect the electric wires and to relieve the strain due to the establishment of the dangerous surges.

Of course, wherever possible, it is the aim of the company to purchase a right of way as direct as possible to the customer, since great expense in both wire and poles with the fittings may be thereby avoided. The poles and towers for high tension work are made quite tall and are spaced at rather long distances, an average being about seven hundred feet. There is a relation of the spacing distance to the height of towers which, if observed, establishes the most economic condition. If the span is very long, the towers must be tall and strong to withstand the great weight and consequent sagging of the wires. This condition means a minimum of towers, but these few become very expensive because of their abnormal height and necessary strength. If they are spaced too close, the large number necessary to cover the distance will increase the expense, but the individual towers will be relatively cheap as they need not be so high. For a pole span averaged between these two, the expense will be a minimum. This ideal span is approximately seven hundred feet.

At least once every mile it is advisable to have a guyed tower or pole thoroughly anchored in both directions of the line by steel anchor or guy wires. This is necessary for a very good reason. Do you remember as children how you used to set up dominoes in a long line, one directly behind the other, so that if one was knocked over the entire row would fall? This same thing would occur if a line were to be broken as the result of an arc, snapping of a tower or other cause. The entire line of poles and

towers would be very apt to collapse, since they could not economically be built strong enough to withstand the pull of the wires unless guyed securely each way at every few poles to relieve the line weight. Whenever corners are encountered, the pole placed there must be securely guyed to support it and balance the strain upon it. Sometimes, on river crossings, spans of several hundreds of feet are used and the wires are held by especially strong towers with strain insulators which likewise are mechanically very strong and insulate the wires. The failure of an insulator in the system may cause damage that only weeks of work and great expense can repair. One can get some idea then why the problem of the transmission engineer is no easy one and why this phase of the whole system should receive the attention that it does, since it is by nature the weak link of the chain.

The size of wire used for this transmission of electrical energy is of great importance in determining the cost of the proposition. Copper wire is itself very expensive. Also the larger the wire, the heavier it becomes, and consequently it demands stronger towers or poles, heavier insulators, and in general proportionately more costly auxiliary apparatus. One may well imagine, therefore, that the determination of the choice of wire is by no means an arbitrary factor. In fact, laws govern the size of the wire, and through these laws engineers can very accurately estimate the necessary size for the most economical and satisfactory results. Many factors influence the size of wire required. Some of these are the magnitude of the voltage and the amount of power necessary to be transmitted; the cost of energy production at the central plant;

the interest, depreciation, taxes and insurance upon the invested capital, all of which constitute the so-called *fixed charges on the line.* In addition, there is the loss in energy by the transmission system. Lord Kelvin, one of the greatest scientists that has brightened the world with his intellect, enunciated a law bearing his name and stating concisely the economics of the size of wire for transmission which is to-day the basis of all calculations. The law is called *Kelvin's Law* of most economical size of wire for a transmission system. It may be stated as fol-

FIG. 138.—CURVES FOR KELVIN'S LAW INDICATING THE MOST ECONOMICAL SIZE OF TRANSMISSION WIRE

lows: that that size of wire for which the cost of the energy lost per annum is just equal to the fixed charge on the capital invested is the most economical. This law is applied with many corrections and additions which makes its calculations sometimes long and involved. This law is most often worked out on the basis of curves which are plotted, as shown in Figure 138, where curve "A" shows the cost of the energy lost per year being radiated off into the atmosphere as heat, which can accomplish no use whatever. This loss is proportional to the square

of the current flowing. This current squared multiplied by the resistance of the transmission wires and by the total numbered hours in the year that this current flows gives the number of watt hours. This result may be converted to kilowatt hours and then multiplied by the cost of one kilowatt hour in order to find the cost of the yearly wasted energy. As the resistance decreases with increasing sizes of wire, the cost also falls off or decreases as the wire becomes larger in size. This is shown in curve A. Curve B of Figure 138 represents the fixed charges on the cost of the wire. Its intersection with curve A shows that these two costs are equal and that the size of wire corresponding to this value and found directly below it in the horizontal axis is the most economical size of wire. In other words, it may be cheaper to waste considerable power per year by employing relatively small wire when the interest rate on money is high. There is another method of economics in this connection that may be applied for determining the most economical value of voltage to employ. Any further discussion of these points, however, would probably rather becloud the issue than clarify it, unless a complete treatment of the subject could be introduced. The desire of the authors in giving even the above facts is to stimulate in the reader an interest in the many applications involved in these apparently simple problems.

Solid copper wire is generally used for overhead transmission. Sizes smaller than No. 8 are never used for outside work since they are not mechanically strong enough to withstand the snow and sleet of winter periods without breaking. But usually the amounts of power to be transmitted call for

larger sizes. In any event No. 8 is the smallest employed. The high-tension wires are not insulated, since there would be little advantage in so doing due to the fact that the insulation could not be depended upon as an insulation; and, secondly, since the insulation would deteriorate very soon through exposure to the weather conditions and might even drop off the wire. In towns and suburban districts, however, where twenty-two hundred volts are usually employed as distribution voltage, insulated wire is used since it does give some insulation protection.

In some of the long-distance transmission systems of the West aluminum wire is used for this purpose. In European countries and in Canada, the use of aluminum wire for overhead transmission has become quite general. It has almost twice the resistance per mil foot that copper has, but, on the other hand, it is almost three times lighter. This means that the wire may be much larger in diameter—a feature that is desirable since the critical corona voltage may be reduced thereby. The aluminum wire is mechanically weaker than copper and it is difficult indeed to solder it for connections, as is done so readily with copper.

Wires have been used with more or less success having a steel core wire with the aluminum wire stranded over it. This gives strength and increases the wire diameter. In some cases also the conducting strands—for the steel is not nearly as conductive as the copper or aluminum—have been held out from the core by collars fitted every few inches. Such a wire seems to have the beneficial characteristics, in regard to corona losses, that a solid wire of the same cross section would have. The weakest

link in the powerful chain, which is slowly but surely girdling our country in every conceivable direction, lies entirely, as heretofore stated, in the insulation medium.

Because of the unsightly appearance and the attendant dangers of the overhead type of power distribution in congested sections of traffic, city ordinances have been enacted to require the electric utilities to employ the underground system of transmission. Each city presented a new problem, different from that of any other city. Here, perhaps, were numerous subways, with rather free rights of way, and there the telephone system controlled the choice of the locations, then the constructional problems with their great expense caused many a financial lion to quake with the dread of the many millions involved in the undertaking. Have you ever looked down through one of the gratings or into some of the manholes of New York City, especially along Broadway? The view will afford something of a revelation and an education of no small interest. You wonder why the street does not cave in. You see nothing but space under the street with a multitude of gas pipes, water pipes, sewer lines, conduits and ducts for power lines, culverts and telephone systems, telegraph, fire alarm and other signal construction. Look at the manhole covers at the junction of a cross-town street and how many do you see? You are amazed to find not one, not three, but probably ten or twelve. Here the art of electrical transmission had to be learned all over again. New data and information had to be gathered and experience gained from investigations of a scientific nature. Much of the most valuable, however, was secured through unscientific methods and became

available through the channels of costly failure. Even to-day, as pointed out in the early pages of this chapter, the records of experience are multiplying and the laws of economics are still being formed for use in the future to guide with more certain steps the transmission engineer.

The underground systems have forced upon the central plants a vast expense during their construction, and at all succeeding periods, because repairs are difficult to locate and to make. On the other hand, an overhead system for all the electric utilities, as the telephone, the telegraph, the fire alarm and the signal systems, to leave out any mention of the vast amount of power and distribution lines, would make a most unsightly as well as dangerous equipment. Through the development of the electrical science, many schemes and devices have come into use to locate quite accurately the position of trouble on a line, such as a broken wire, or a grounded cable, or a cross on a pair of wires. Measurements may be taken with that degree of precision that the fault may be traced from the plant within a few feet of its actual position.

Starting out from the power house itself are the feeder circuits which run through the ducts for possibly miles to the various substations, where the electrical energy may be converted into direct current for traction service. It may also be transformed down by large transformers, which may be as high as fifteen thousand volts down to values suitable for distribution over a limited section. Such voltage is usually twenty-two hundred. Then smaller transformers, called *distribution units*, step that voltage down at the customers' to the value

desired, be it one hundred and ten volts for lighting or other higher values for motors. These feeder lines radiate out like the ribs of a fan from the central plant. Again, from each substation radiate other lines like many smaller fans. The central

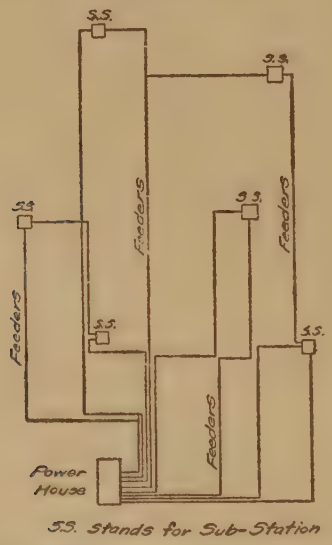


FIG. 139.—FEEDER SYSTEM FROM POWER HOUSE TO MANY SUBSTATIONS, ALL BEING TIED TOGETHER IN OPERATION

plant, however, does act in the capacity of a substation also in radiating lines to the near-by consumers. These transmission lines will be grouped into main-channel ways as far as is consistent with economy. It is advisable, however, by all means, to have the main lines from the central plants to the substations, when there are more than one, follow different routes, since continuity of service is more certain by such design than by running

these lines in the conduit. A layout to illustrate this point is shown in Figure 139.

At cross streets taps are made in the manholes for supplying the customers living along these, and these lines are tapped again into the lines at the next parallel main line. Whenever possible and convenient, such cross connections are made which serve to tie all the lines together and form the so-called *networks*. By properly formed networks of conductors in such a system the voltage drop on a system resulting from an unusual demand of power is reduced to a minimum. This is obviously true, since the energy may arrive at the destination through not one cable, but rather by many parallel lines all acting together, so that the combined resistance to the flow of current will be a minimum and considerably less than that of one line alone.

Consider Figure 140 where a direct current feeder is connected by a loop system from the station out around several business blocks, let us say, and thence back to the plant again. The street lines cross and recross as there seen.

The lead-covered cables as they emerge from the ducts at a manhole are supported on shelves or hooks around the manhole separated at a safe distance, determined by the potential that they carry. Perhaps you have seen the electric company's men feeding great lengths of lead cable down into one of these manholes from huge wooden reels. This cable is in the process of being pulled through the ducts for either new lines or for reconstruction. Winches pull from the far end and the men push the cable as it is fed in from the reel end.

The snake wire to which the cable is fastened is passed through by the following method. Wooden

rods of short lengths are jointed together and are pushed through as fast as the joints can be made. After such a continuous pole extends from one manhole to the next, a piece of cord is attached to the

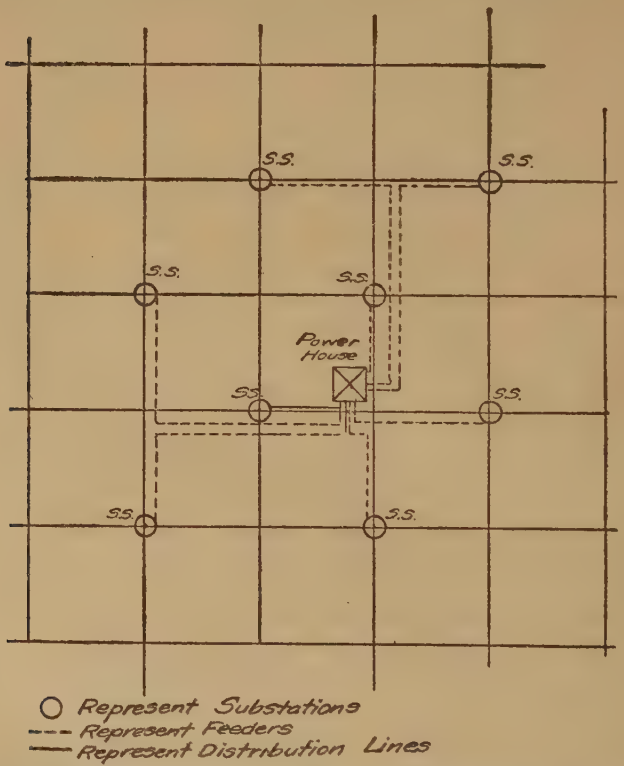


FIG. 140.—DISTRIBUTION SYSTEM OVER A TERRITORY SUPPLIED FROM SUBSTATIONS PROPERLY LOCATED

near end where the process was started and pulled through by means of the jointed rod. In the process the rod is taken apart piece by piece. To the cord is now attached the pulling wire which is very

strong and which in turn is pulled through. The far end may be attached to a winch and the near end to the end of the cable, and by the pulling and pushing procedure the cable will be finally drawn through. The conduits are constructed in various numbers of ducts from one alone up to a great many, sometimes twenty-five in one conduit. It is not advisable to place more ducts than this in one

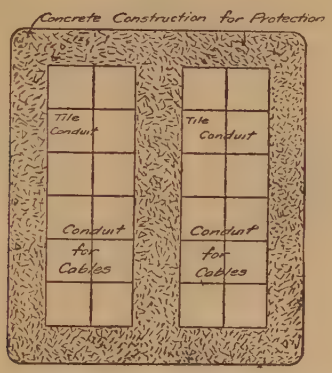


FIG. 141.—A CONDUIT SYSTEM LAID IN A PROTECTING INCASEMENT OF CONCRETE

conduit, since damage to one cable may injure several adjacent ones and disrupt a large area of service. There may even be several of these laid side by side where many circuits are running in the same tunnel. These ducts are set upon a concrete bottom, and the concrete is poured in, around, and over them, forming a complete water-proof vault of several (five to six) inches thickness. This vault is intended not only to exclude moisture but very largely to prevent danger from crushing by weight from above or by accident. Figure 141 shows an arrangement of ducts for a large line. The manholes

are usually constructed of brick and should be deep enough for a workman to clear his head, about seven feet, and fitted for drainage in the bottom for keeping it dry and carrying off rainwater that will find its way in. Figure 142 shows a square man-

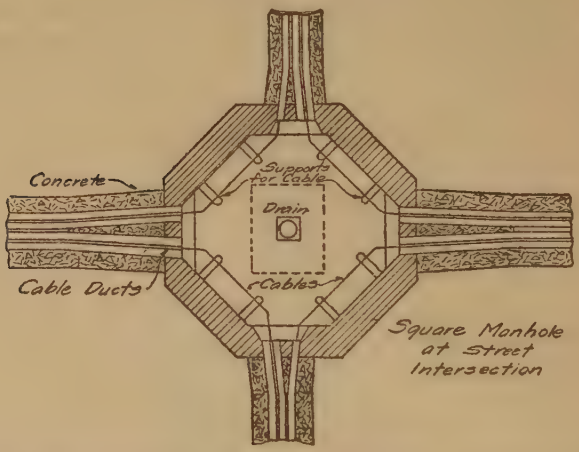


FIG. 142.—A SQUARE MANHOLE AT STREET INTERSECTIONS WHERE FEEDERS MAY BE TAPPED

hole of popular construction with the main line and branches passing through.

The arrangement of the feeders and circuits within these conduits is a matter of considerable importance and requires much study. If many small consumers are to be supplied along a certain route, one feeder of ample capacity may be employed for this purpose, tap-offs being made at the proper locations. Where large loads, however, such as department stores, are to be supplied, individual lines may be run directly to them at high voltage with the necessary transformers placed near the store in con-

venient manholes or perhaps in a substation. When low voltage distribution is made over a certain territory, there must be a great outlay of capital in the large amount of copper necessary. There is, as one can see, a balance of economy here between the cost of copper, when low voltage distribution is employed, and that of the cost of additional transformers for reducing the high voltage more often for the customers of greater importance.

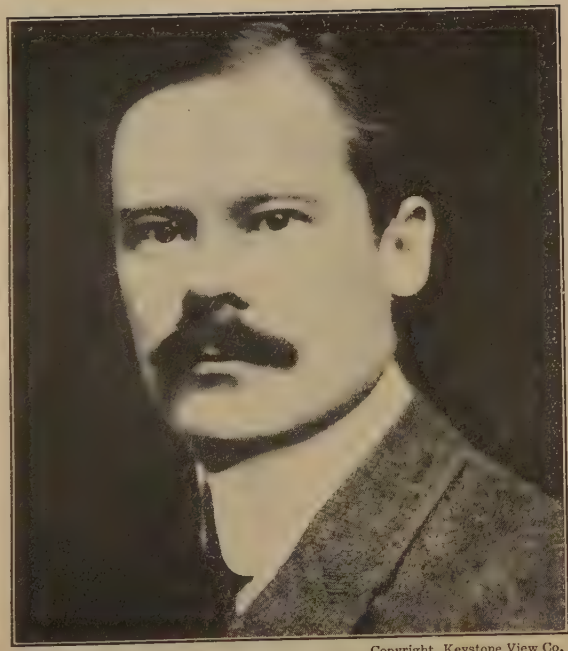
CHAPTER II

ELECTRICAL PROTECTIVE DEVICES

DURING the past decade a crusade of powerful influence has been waged against the various forms of carelessness that have led to the thousands of accidents annually reported to the shame of the Government and its public and private utilities. These accidents at times occur through gross neglect of the operators and workmen themselves, but frequently, also, through the lack of establishing precautionary measures on the part of the companies. In any event, the press almost hourly publishes pathetic accounts of the loss of life and of the sadness that prevails for weeks and months in the homes of those who have lost dear ones. It is then that we rise up against the army of the careless; it is then that commissions are born for investigation, and die soon after the harvest of easy coin has been reaped; it is then that attention is again directed toward this safety device and that, to supply through mechanical means the protection that cannot be secured through human control alone, since the latter is subject to inefficiency and uncertainty. Expert and trained engineers are therefore constantly called into conference to solve the problems of *safety first.*

Perhaps no period of time has been marked so unmistakably by the effects of a popular slogan as has the past ten years during which there has

CHARLES P. STEINMETZ



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GUGLIELMO MARCONI

been a nation-wide cry of "Safety First." Where do you see this sign? Perhaps it would be more simple to ask where it is not seen. Every place that hides the avenging hand of injury has been placarded with such an emblem. The lurking dangers of many localities and of many operations have been clearly indicated and the signpost erected to show the way to safety. It has been taken up by every profession—safety codes for life have been printed and distributed broadcast in many vocations. The legislators of our land have had the honor of constructing laws demanding that certain types of dangerous work be restricted or the workmen protected as far as possible. Workmen's compensation laws and proper and adequate lighting facilities have played a most important part in bringing to terms the delinquent factory owners who cherish the dollar at the expense of the best in a man's life. The regulations against overhours, and the penalties for the employment of child labor have been a safety-first move and have directly had a more beneficial effect upon the health and wealth of our nation than have any other known factors.

You may fail to see the connection between these thoughts and the chapter heading. The above references, however, to the devices for protection of human lives will emphasize the corresponding necessity for protective devices for any type of system which in its action will approximate human intelligence and operate for human comfort. It must certainly have been noted from time to time during the discussion of the past chapters, that if continuous service is desired or in some cases even demanded, protective devices must be employed to preserve this service in spite of certain amazing

and detrimental influences that almost daily become evident.

When, as individuals, we find that we are overworking mentally and physically to the extent that we become exhausted, we strive at the earliest opportunity to "let up" to a certain extent in the undue expenditure of energy. This is not so true in the case of the inanimate electric circuits, machines, and other mechanical devices. These are constantly in danger of overworking and of destroying themselves in the process, unless some protection of a mechanical nature intercedes in their behalf to either reduce the load demands or to call the attention of operators to their difficulty and thereby bring about the necessary relief.

You have had the sad experience perhaps of connecting an electric heater or possibly a flatiron to the circuit at night when many of the lights have been on, and thereby have caused a fuse to blow out on your main incoming circuit, with a resulting darkness for the remainder of the evening. Your circuits were loaded nearly to capacity by the lights burning in the house and the addition of the energy for the heavy current apparatus caused an overload which might have occasioned danger to the house and its contents, since by overheating circuits fires may be started in most extraordinary places. Any such catastrophe, however, is avoided by a blown fuse which announces to the household that you have violated your contract, so to speak, between the wiring system and yourself. Such fuses are usually plugs with the standard Edison base made to screw into a socket resembling the ordinary lamp socket. These fuses are, however, directly in the line as a part of the wire circuit itself. The

heat produced by the excess current melts this piece of fuse wire, thereby opening the circuit.

These fuses may run up to thirty amperes in this plug type for 110-volt lighting circuits. You must understand that overloading the circuit as above explained really constitutes the minimum of such hazards to a circuit. Very often indeed, short circuits in a system occur possibly by the filament of a lamp becoming burned out and welded together or by the wires of an iron or other heating device becoming charred and in contact with each other at the point where they connect with the device. Such impending difficulties are usually guarded against by the best design that is consistent with economy and appearance, but, even then, they occasionally occur when least expected. In case of such short circuit, the only resistance opposing the force of 110 volts is that of the solid heavy wire, and hundreds of amperes would flow unless protected by the fuse. Any such current passing through the small wire used for ordinary house wiring would result in the circuit becoming red hot, burning the insulation, and setting fire to the house.

Of course, it is very desirable and really essential that excessive overloads be guarded against by protective devices, but the circuits and machinery must also be protected against short circuits to insure them from almost instant ruin. Fuses are very effective instruments for overload and short circuit protection. They are used on small motors and on practically all types of electrical appliances where frequent blowing of the fuses is experienced. Of course, they must be replaced as they are blown out. If this renewal process is a frequent one, the expense involved in the maintenance of the safety

protection becomes large. In such cases it is more economical to employ for the purpose circuit breakers which cost considerably more originally than do fuses but which have practically no maintenance cost at all. Fuses are made up to very large sizes in the so-called cartridge type. These are of a fibrous material and are tubular in shape, inclosing the fuse wire and a dry powder for smothering out the arc that forms upon the breaking of the circuit. The fuses are made with either ferrules, in the small sizes, that slip into spring clips, or of blades on the ends for large sizes, where they are pushed in between contacts as a switch blade closes into the contacts. The largest sizes of such fuses are of the order of eight hundred to one thousand amperes for circuits having 250 volts or less. Those used on voltages as high as six hundred are made not greater than 100-ampere capacity. The arcs with higher voltages have such force to maintain the arc that the manufacture of fuses therefor is discouraged and the use of circuit breakers for such circuits is recommended. Circuit breakers are always employed where large amounts of power are to be controlled and where a circuit is frequently interrupted in service.

Fuses are not reliable in their operation to the exact rating stamped on them and, moreover, may even take a considerable overload for a few seconds. This characteristic makes them particularly suited for circuits. In case of a very heavy overload or of a short circuit, their operation is practically instantaneous, but with a small overload which lasts for a few seconds only the circuit may not be opened. This is a desirable feature since no harm from a short overload can result. In fact,

there are mechanical devices called *inverse time switches* that are employed in large power houses and on feeder lines and for customers employing energy in large amounts. A multiplicity of fuses, however, in a circuit should be avoided since circuits are sometimes unnecessarily interrupted by the premature blowing of a fuse nearer the source than the immediate one. Yet a fuse should cover only a small area in order that the least inconvenience be realized by its operation. They are usually made of alloy metals having a low melting point. Sometimes copper and aluminum are employed and calibrated for this purpose when the large current fuses are installed.

For the protection of large motors, generator equipment, individual circuits from switchboards, feeder lines and the like, circuit breakers are usually employed. For direct current circuits, direct current circuit breakers are employed, which are in general of two types, one called the *magnetic blow-out type* and the other, and more common type now in use, called the *carbon-break type*. For service on alternating current circuits, there are alternating current breakers, which may be of the air-break or the oil-break type. That is, in the one case the contacts open in air and break the arc as in the direct current breakers for use only on low voltage systems, and in the second case the contacts open under mineral oil which has a high flash point and is free from water and serves to quench the arc that follows any such break on a high voltage and large power supply. Figure 143 shows a simplified diagram of the parts of a circuit breaker where the parts of special note are the contacts at "C," the solenoid "M," plunger "p," release "d" and spring

"S." When the current exceeds a certain predetermined amount, the magnetic strength will have increased enough to lift the plunger "p" with a sufficient force to unlatch the release "d" and by virtue of the coiled-up spring "S" the contact at "C" is broken, and the circuit is thereby opened. By screwing up the thumb nut at "a" and raising the plunger "p" nearer the center of the magnet

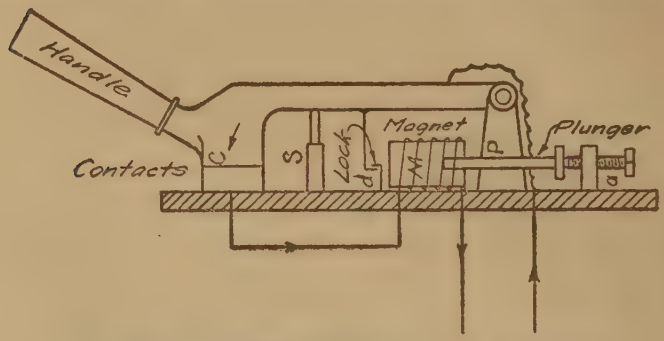


FIG. 143.—SIMPLIFIED DIAGRAM OF AN AIR-BRAKE CIRCUIT BREAKER

"M," the plunger can be sucked up through the coil by a less current. By varying the position of the plunger in this way, the breaker can be made to operate at any desired current.

Most of these large breakers now employ the carbon break as a means of reducing the flash and also of reducing the wear on the copper contacts. The carbon tips close first as the breaker is set. Then the great heavy sliding brush contacts close. On breaking, the main copper contacts separate first, followed by the carbon tips above. The principle is that as the copper surfaces separate, the carbon tip circuit, being in parallel with it, carries the current and therefore there is no arcking at this point

of break. As soon, however, as the carbon tips alone comprise the circuit, the resistance of this circuit throttles down the flow of current, so that upon the final rupture of the circuit the arc is not as great as it would have been upon the separation of the copper contacts alone. Furthermore, the carbon tips are better able to stand this arc since the melting point is so very high that little injurious effect is made upon the carbon surfaces. As they do wear away, however, by disintegration they may be replaced in a few minutes and at very slight expense. Such carbon-break circuit breakers are now seen on practically every direct current switchboard in the country. The magnetic blow-out type, as explained in an earlier chapter, has found extensive use in the trolley cars and in other smaller breakers, and has been found to give good service. But even this principle now takes a less prominent position in the light of the more desirable type above explained. A view through the window of some large substation for the traction service would suffice to give one the details of such a breaker and to impress one with its massiveness.

The one characteristic that is undesirable about these circuit breakers is the fact that they always open when the current reaches the value for which they are set. They have no inverse time feature inherent in them as was characteristic of the fuse wire, which was explained in detail under that heading. A small momentary overload operates them instantaneously as do also the short circuit demands. There may be devices employed in conjunction with these breakers, however, which will trip them out and will operate as inverse-time elements. There are relays connected into the circuit and as such

act as the brains for the huge breaker. These relays operate a secondary circuit, which in turn excites the electromagnetic hammer and thus actuates the tripping element of the breaker. In other words, then, the breakers are remote controlled, and the actuating element is a small device which directs the opening period of the main breaker with a time relationship that depends upon the intensity of the current flow. If it is a short circuit, immediate break is demanded by the relay. If the current exceeds the normal full load by only a few per cent, the circuit may not be opened for ten seconds. If the overload is quite heavy, the time may be reduced to four seconds before opening. Such relays are not customarily operated in conjunction with the direct current breakers. In alternating current operation, however, such control is in most approved practice. The switchboards employing the use of large direct current breakers utilize a form of protection, called *flashboards,* between adjacent poles of the apparatus. They are partitions of either slate or fiber, placed between the adjacent poles of the same breaker, when it is a two or three-pole breaker, or surrounding a single-pole breaker to protect the equipment on the adjacent switchboards from the heat of the arc.

The alternating current circuit breakers of the electromagnetic type may be constructed like the direct current type in every way except in the design of the alternating current magnet. The core and iron associated with its action must be laminated in order to reduce the loss of energy as heat caused by the eddy currents. Such breakers are made only in the small sizes and for low voltage. Since most alternating current potential employed

in distribution from switchboards and the like runs from twenty-two hundred volts up, the oil-break type of circuit breaker is in more common usage. See illustration for a circuit breaker with the casing for containing the mineral oil lowered to expose the contacts. The one shown is a relatively small capacity breaker for a three-phase system and is hand operated through a system of levers from a handle on the front of the board. Large breakers which interrupt the flow of several thousand amperes under several thousand volts pressure have the individual line contacts separated in a tank of their own which is built into brick or concrete cells for protection from explosion and fire hazard. Such switches are very heavy and are invariably operated from motors mounted above. These motors are controlled through the intermediary action of the relays.

These oil switches, as the oil-break circuit breakers are often called, for purposes of brevity, may be operated or controlled by many different types of relays, all of which have been designed and constructed with care and often with great expense to accomplish the many special requirements imposed upon them by the conditions of practice. Some circuits require the overload type of relay; whereas on other circuits the inverse time feature is desirable. Where certain types of circuits are employed and particularly where the supply is through several parallel feeders, a reverse power relay is of utmost importance to the continuity of the supply. This relay may be used in conjunction with either of the above types. The various applications of these relays constitute a fascinating page from the record of electrical achievements. It is therefore to be lamented that a mere example of their use must

suffice here. It is true that there is a vast number of arrangements and connections possible in these relays to accomplish the desired results. These arrangements introduce complications of an intricate nature, but the fundamental ideas may be imparted without going into minute details of the problem.

Of course, it is the fundamental purpose of the automatic circuit breakers to protect the circuits for the power corporation, and if possible to insure continuous service and also to protect the apparatus of the customer by disconnecting his equipment from the system to prevent injury. Naturally, an overload relay to actuate the breakers at the customer's plant will immediately disconnect his equipment from the dangers of the tremendous power operative as soon as he overloads his machinery. Each customer should in this way be protected. It is desirable that the distribution circuits and particularly the feeders to substations be not interrupted in the transmission service by any momentary loading of the circuits. The system and the equipment of the company should be protected from any tremendous demand as a dead short circuit. Many times troubles of a really serious nature right themselves in a second or two. Here, the inverse time relay finds its application. The point of supply is the proper location for these relays. Their operation is dependable for the value at which they are set. They are small devices somewhat like small watt-hour meters used in houses and they are usually located at the bottom of the switchboards. Their price varies from $25.00 to $100.00, depending upon the special features.

The arrangement of relays on a circuit must be such that a short circuit between any two lines will

cause the breaker to operate. On a single-phase system, one relay is sufficient to accomplish this result. On a two-phase circuit, it is desirable to have a separate control for each phase, since a fault on one phase alone may permit the other phase to continue in operation where lighting and motors operate from the same system. This means, of course, that there must be a relay in each phase. Thus two relays are required in this case. In the three-phase systems, there are in general two ways of operating the system. In one, the neutral point is not connected to the ground, and in the other, it is connected to the ground. These are called respectively the *ungrounded* and the *grounded* three-wire three-phase system. Each system has its advantages and disadvantages, but, at present, usage seems to be favoring the grounded neutral. A fourth wire is sometimes run on the grounded neutral system from the neutral, so that two voltage ranges on a Y system is made possible, where one is the square root of three times the other. On such a system, three separate circuit breakers are recommended and these require a relay in each phase wire. If any phase wire becomes grounded, the individual breaker will open up and clear that phase only and leave the remainder of the circuit intact. A short circuit between any two phase wires should open the two breakers and cut out the two phases, although only one may operate. In this event, two phases would remain undisturbed. Where the three-wire three-phase ungrounded neutral system is used, only two relays are required to operate a three-pole switch. This type of connection will trip out the entire circuit when any one relay acts.

It must be understood that the coils of these relays are not themselves connected directly into the main lines. This would require that they be large and ungainly, since the copper circuit might have to be of huge size. These relays come under the head of meters, and meters on a switchboard or other heavy current-carrying system in alternating current are never connected directly into the lines, but are rather connected to them through intermediary devices called *instrument transformers*. These were not discussed in Chapter XV of Volume 6 which dealt with power and distribution transformers, but were reserved for discussion in a succeeding chapter on meters. A word will suffice, however, to define the two general types, *potential* and *current transformers*. A current transformer consists of a primary of one or more turns with the secondary circuit wound on the iron in such a way that the current flowing in it is always in exact ratio with the primary current. This ratio of the current transformer may be four hundred to five amperes, a relation which means that when a five-ampere ammeter, which is connected to the secondary terminals of such a transformer, reads just five amperes then in the main line, or primary, there are just four hundred amperes. Proportionate line currents register proportionate values on the five-ampere indicating meter. The line current would always be formed by multiplying the ammeter reading by the ratio 400/5 or 80. The primary coil of such transformers is employed for insertion in the main lines. The secondary circuit, however, which is nearly always designed for five amperes, operates the relays, which in turn, by a system of contacts, close the low voltage remote control system that

operates the oil-switch motor. The potential transformer for instruments is made to be connected directly across the line as a voltmeter is connected, and it is always a step-down arrangement with a definite ratio such as 2,200 to 110 or 33,000 to 110. These transformers have a primary system designed

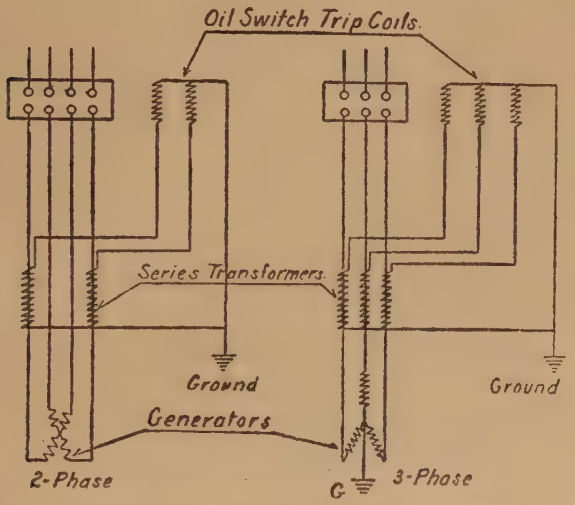


FIG. 144.—ELECTRICAL WIRING FOR CIRCUIT BREAKER PROTECTION

to be placed directly across the voltage of the system. This steps-down the voltage in a certain ratio that makes it readable on a 150-volt meter. Figure 144 shows how these transformers are connected to the relay coils on the various phases of the systems discussed above.

Although considerable has been said about these little relays and about the wonderful work that they accomplish, as they act with almost human intelligence on a system, a word or two will be added con-

cerning their operating features. There are in general use two methods by which they derive the motion of their moving element. One is the so-called plunger type or method, in which a solenoid is sucked up; whereas the second is called the *induc-*

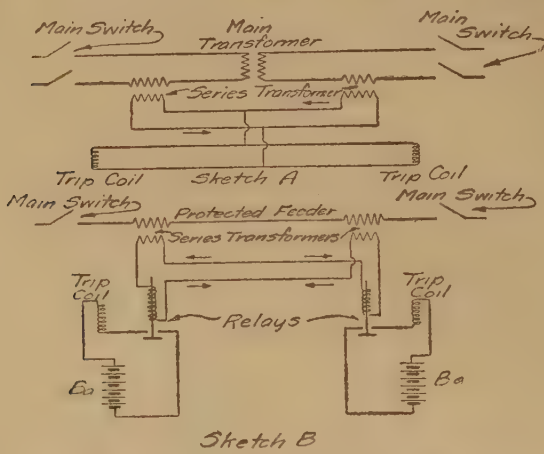


FIG. 145.—RELAY CIRCUITS FOR THE PROTECTION OF MAINS, FEEDERS OR GENERATORS

tion type which operates as an induction motor does in the alternating current house meter. The means for regulating the operation of the relay for a particular current value is obtained in the solenoid plunger type by raising or lowering the plunger as described for the current setting of the circuit breaker of Figure 143. In the induction type relay, however, the current adjustment is made by varying the spring tension that opposes rotation. For the time element in the plunger type, the movement of the plunger is retarded by means of an air bellows or oil dashpot, which may be arranged to suit the requirements. On the motor type relay, the

retarding time element is obtained by a disk revolving between strong horseshoe magnets. Adjustment of time is made by varying the positions of the magnets in respect to the axis of the disk. Figure 145 shows a typical example of the balanced arrangements of the relays for the protection of a feeder circuit. As soon as the relay operates and closes the battery circuit, the main switch is immediately tripped out.

The use of the *reverse power relay* in opening up a circuit becomes quite obvious if we consider a simple diagram as in Figure 146. Suppose a bus-bar system in a power house is supplying energy by two main feeders to a substation some three miles distant. At the bus bars there will, of course, be inverse-time relay-operated circuit breakers and at

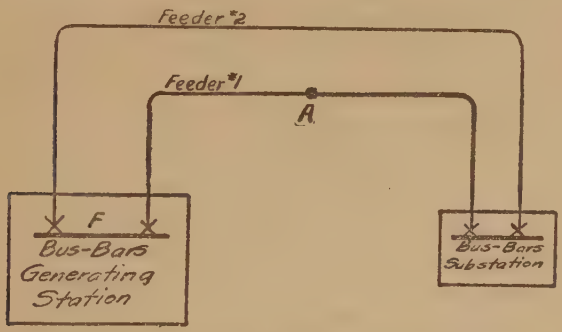


FIG. 146.—FEEDERS TO SUBSTATION PROTECTED BY REVERSE POWER RELAYS

the substation the same type, since that virtually becomes a generating plant considered from the distribution point of view. These two feeders are, of course, in parallel, since one feeder cannot supply all the load required. It is also a point of safety to

have two in the event of the failure of one cable. Now consider a short circuit at "A." Energy will flow from the bus bar "F" to the short circuit at "A" through feeder No. 1 and through feeder No. 2, the substation, and back over feeder No. 1. That is, power flows from bus "F" to the short circuit at "A" from both ends of the feeder. This would mean that the breakers at bus "F" on both No. 1 and No. 2 feeders would trip out, thereby isolating the substation, and feeder No. 2 would be doing no good as a safety or auxiliary line. If, however, at the substation, feeder No. 1 had a relay which would trip out the breakers only when power flowed in the reverse direction to what it should, then feeder No. 1 would be cut off from the bus bar at "F" and also at the substation; whereas feeder No. 2 would continue to carry load to the substation. Such a reverse-power relay-operated oil switch meets an important need in the parallel operation of feeders to a point from the same generating station. When the line has been repaired, it may then be placed back in use again. Sometimes important customers are put on one circuit that is protected by relays in such a way that if a line fault develops between customers, the faulty section is cut out automatically and the customers continue their service by drawing energy from the other direction. These customers, of course, have explicit contracts calling for uninterrupted service under penalty to the company.

The above protective devices are by no means the only ones that protect the electrical systems from damage. There are speed limiting devices employed on rotary converters to trip open the direct current side in case the speed exceeds a certain safe value.

Also a speed limiting device is employed on steam turbines in order to keep them from operating at excessive speed and thereby damaging the rotating part. In that case, the device operates an emergency valve on the main steam supply which shuts down the machine.

There are reactance coils, called *current limiting reactances* that have a useful purpose in generating stations to protect the generating units themselves from supplying damaging amounts of power in the event of short circuit. These generators are often connected to the bus bars through the reactances. Sometimes the sectionalized bus bars are connected to each other through such reactors, and sometimes the reactors are placed on each main feeder leaving the plant. The purpose of this device is to protect the system from the tremendous amount of energy that might flow when a short circuit occurs on the system. The generator with its designed reactor may not give on a sustained short circuit more than ten to twelve times full load current; whereas without such protection the currents may be over forty to fifty times the full load value. Sometimes the generator is connected directly to a section of a bus bar through the reactor and the transferring of the machine for paralleling or for auxiliary bus maneuvering is done with the bus section as a unit. Some systems, where the plants are very large, employ complicated systems of transferring and switching of machines to give the flexibility desired.

Of course, lightning arresters have been employed for years in one form or another for protection of the circuits, equipment and the like, from surges due to lightning strokes, opening switches, and the throwing of large machines suddenly on the line.

The horn gap has been referred to already in its connection with the aluminum lightning arrester. The choke coil should be used at the end of all long distance transmission lines to increase the impedance of the path through it and to form a relatively easy path to ground by way of the electric relief valve, *the arrester*. One type of arrester employs a series of zinc cylinders with gaps between them which extinguish the arc at the period that the cycle is passing through zero current. The zinc, being a non-arcking metal, does not form conducting vapors to sustain the arc during the zero current points in the cycle. This is important since the arrester should be a relief valve to the abnormal voltage of the system but not act as such to the normal voltage. These multigap arresters are used for low voltages only; whereas the aluminum arrester is employed on the highest voltage systems now in use. Telephone and telegraph lines are also protected from lightning discharges and strokes by a type of arrester where the circuit itself and the ground connections are separated by a thin piece of paper. Any abnormal voltage punctures this paper and places the line in contact with the ground so that complete discharge and full line protection is given. The perfect type of arrester would be one that would operate on the electrical circuit just as the safety valve acts to a steam system. When the pressure exceeds a certain normal amount, the valve opens and continues open until the normal pressure has reestablished itself. Instead of the energy flowing into the air as the steam energy wastes itself, the electrical energy discharges into the ground.

CHAPTER III

INTERIOR WIRING

AMONG the greatest achievements of the electrical industries of this country none stands higher than does that of electric lighting. Practically one quarter of a billion lamps were manufactured and used last year in this country. This would indicate that electricity for lighting has come into quite general use. Indeed every town or community should, with pride, proclaim its use of electricity for illumination and for the industrial utilities that mean convenience, comfort, increased production, reduced fire hazard and growth in all departments. Particularly important is the reduced fire hazard. Recall for a minute the days when electricity was too young and untried to be in popular use. The manufacturers at that time were compelled to use steam engines almost exclusively with the boilers fired by coal and gas. These were perhaps small and several were needed to supply the energy. The office buildings used gas for illumination and the home utilized gas when it was available; but oil lamps were almost the invariable solution to this problem of home lighting. Such utilities had a very high fire risk and the business and home were in constant danger through exposure to open flames. At present, an industrial plant needs only a relatively small heating plant since the entire motive force necessary for the industrial

activities may be supplied through electrical energy with a minimum of fire hazard and at a cost much lower than that of the old system of steam plant and belt drives. Now, the up-to-date plants have a motor of just sufficient capacity to drive the individual machine. The long lines of shafting with the belts have disappeared. The shops have been made cheery by better lighting, since there are no belts to exclude the daylight or to obstruct the artificial illumination. The first cost of the individual drive for machines by motors is relatively high; but this money is soon poured back into the coffers of the company by the increased efficiency, by less waste in production, less risk to workmen and less upkeep in general. The lighting of industrial plants has become an art, which is slowly but surely growing into the greatest importance. As already mentioned, many of the State laws now enforce protection to the employees by regulating the minimum amount of illumination permissible in factories and industrial plants. When more States incorporate such legislation and greater intelligence is displayed in regard to such vital points, our country will have taken another step toward placing it in the forefront of the nations of the world. Such enforcement by law would have, as a matter of fact, to be only temporary, for as soon as such general advantages as increased production through the resulting improvement of the morale of the employees, and the better sanitation of the shops, to say nothing of the saving of materials, becomes better known, they will be self-imposed. Investigations in this country and in England have disclosed some very remarkable facts in this relation. These have led to the establishment of certain principles that are slowly

causing a reorganization of the old plants on a new working basis.

The wiring of these great buildings and of the myriads of homes, small and large, in our great land have made a demand upon the contractors in the electrical construction enterprises which stimulated their growth in regard both to number and strength. The demands for such installations of electric power and illumination caused at the very start new companies to spring into existence. Many of these concerns were ill-equipped in the knowledge required for the efficient conduct of their profession, while others were controlled by unprincipled men greedy for gain and not willing to be honest and upright. The public were at the mercy of these contractors who installed many faulty installations which later caused grief by accidents and fire risks.

Several of the national organizations that were interested fundamentally in this unfortunate condition, such as the architects, builders, electrical engineers and contractors and insurance organizations, formed into a body called the National Board of Fire Underwriters to establish a regulation code as a guide to approved electrical construction. Inspectors were maintained to investigate the work and to pronounce approval or disapproval in view of the code of rules. Insurance on the buildings could only be procured through an approved report on the wiring. The report was in form of a certificate of the Board of Underwriters. As the art of illumination advanced and new precautions seemed necessary, new regulations were added and the old ones revised. A new edition now appears every two years. Furthermore, to protect the public against inferior quality of materials, a laboratory was es-

tablished to examine and test every fitting and type of material used and placed upon the market. If the product met with the approval of the examiners, a stamp bearing the Underwriters' Laboratories Inspection was either placed upon the material or it was listed among other materials of various manufacturers to indicate that it had the necessary approval. Further, no wiring installation would be accepted by an inspector unless the fittings and materials were found on the "approved" list. Thus the public is protected from a danger, the immensity of which is realized by few, by a system of most judicious regulations. The unscrupulous contractor even now is caught at times employing materials that appear standard, and yet upon careful investigation have proved to be notoriously fraudulent.

The cities and towns of our land adopted the National Fire Underwriters' Code of Regulations either completely, in part, or else formulated a code of their own. Many cities make regulations that are even more stringent than those of the Underwriters' Code in some particulars and for local reasons. Sometimes these additional regulations are wise and sometimes they are quite the reverse. In such event, however, they are usually not contrary to those of the Standard Code, but merely additional. When contracting is done in a city having its own code, both the Fire Underwriters and the city require certificates of approval of the work. Before starting the work, the contractor customarily files such announcement at the offices of the above commissions. Then, during construction, the inspectors sometimes visit the work to see how it is being installed. But, upon completion of the work, the inspectors must make a thorough inspection.

There are in general two classes of wiring, one in buildings under construction and the other in buildings already constructed. The former type, of course, represents less difficulty in wiring and is less expensive for the same class of electrical construction. The wiring of finished buildings requires the tearing up of floors and additional labor difficulties that are not presented in the wiring of the unfinished building. The type of construction called the *fireproof type* requires the greatest attention and is usually more expensive to install than is any other type of building.

The wire may be laid in a building by several different types of construction. These may be enumerated as follows: 1, rigid conduit; 2, flexible conduit; 3, armored cable; 4, molding (metal and wood); and 5, knob and tube. These various systems of installing the wire circuits have their advantages and each has its place. The type of construction and the available funds for the work quite clearly dictate which system is most applicable. Each one of the above systems will be considered and the most desirable applications enumerated.

Consider first the installation of the rigid conduit type of construction. The conduit consists of soft steel pipe cut in standard ten-foot lengths, quite similar to the ordinary gas and water pipe, and has the standard pipe threads. It is made in the nominal pipe size, such as for example three-quarter inch and two inch. These dimensions refer to the approximate inside bore. Conduit couplings and standard bends may be obtained for joining the lengths and forming curves. The best method of securing the proper bends, however, is to bend the pipe as desired, since the soft steel of which it is made readily

permits of such treatment. Where several parallel circuits of the conduit are run, and where the sizes of conduit vary, the only way to produce angle bends of the same concentric amount is by bending the conduit according to requirements. The conduit must run in rigid continuity from one outlet to another. These outlets occur wherever a switch, light, or other device is to be located. The conduit terminates in an outlet box of metal construction to which it is made rigid by means of lock nuts. These outlet boxes afford a space for the wires to be tapped for the branch circuit. Such construction when completed is continuous from the supply end throughout the building to every outlet location. This conduit system may be put in while the building operation is in progress. Then, after the building construction has been completed, the wiring may be pulled through from outlet to outlet and the fixtures and attachments then connected so that the system is electrically complete. This construction represents the best practice. If, at later periods, the wire becomes damaged, it may be pulled out and other wire introduced without disturbing the building construction at all. This represents a very desirable asset. This system is more expensive than the others in first cost; but it is most highly recommended and has the minimum fire hazard.

If the work is to be exposed, the conduit system is best since the wire is protected effectively from any ordinary disturbance. When the wires leave the conduit in the exposed wiring, there are many kinds of conduit fittings which may be purchased to meet almost any requirements. The concealed type of rigid conduit is employed in the majority of new construction now going up in the city, such as apart-

ments, office buildings, theaters and public buildings. In shops, factories, and various industrial plants where most approved wiring is desired in order that interruption to their service may be reduced to a minimum, the exposed conduit system is used, employing the necessary conduit fittings for attachment of accessories and for connection to the ma-

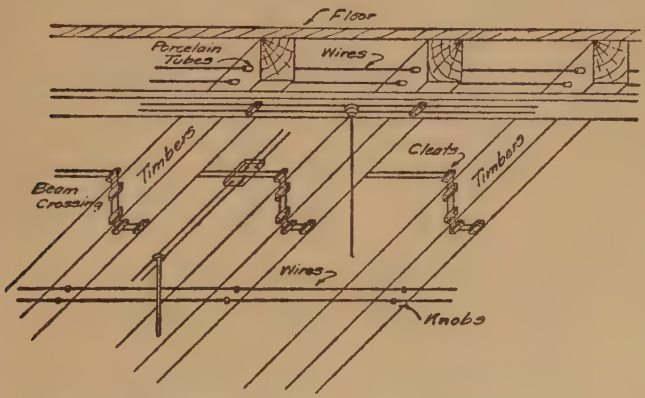


FIG. 147.—TYPES OF OPEN CONSTRUCTION ELECTRIC WIRING

chines. A type of wiring still commonly installed in shops and factories, where the appearance is not of first consideration, is that of the open type of wiring which is supported from cleats and knobs on the ceiling or walls. Such a system is shown in Figure 147. The Underwriters do not permit more than four two-wire or more than three three-wire circuits in one conduit. It is very important that all the wires of the same circuit be placed in the same conduit when alternating current is used; otherwise the conduit would be heated to a dangerous temperature due to the hysteresis loss involved in the iron or steel conduit.

For "pulling in" the wires for either a concealed or an exposed system, a "snake" or fish wire may be used. This is made of flat spring steel. If the wire is very heavy, however, a steel cable may be used to better advantage. The "pulling in" process may be aided by introducing powdered soapstone or talc into the conduit. Never should grease or oil be used as it softens and ultimately destroys the insulation of the wires.

In general, there are two distinct types of insulated wire. One of these is called *rubber insulated,* and is always employed for work in metal conduit systems. The other is known as *weatherproof* or *slow-burning insulation.* This is employed in open wiring and never in conduit or metal molding. The rubber insulation deteriorates under heat more readily than does the other type of insulation and, consequently, has a less current value allowable under the regulations of the Underwriters.

A table of allowable current-carrying capacity for wires is herewith given:

CURRENT-CARRYING CAPACITY

Wire Gauge in B & S Units	Amperes for Rubber-Insulated Copper Wires	Amperes for Copper Wire with Other Insulation
14	15	20
12	20	25
10	25	30
8	35	50
6	50	70
5	55	80
4	70	90
3	80	100
2	90	125
1	100	150
0	125	200
00	150	225
000	175	275
0000	225	325

The following important point should be emphasized. The conduit system is rigidly and metallically complete. Therefore, in case a wire by abrasion of the insulation, by short circuit, or by any other means should come in contact with the conduit, the conduit might become charged to a dangerously high potential. If, however, the conduit is connected to the earth by clamping securely a wire from the metal conduit to a water main or gas pipe, the conduit will always be at zero potential and the maximum possible potential will be that available between the two wires.

The next type of construction is that of the flexible conduit. This also is a highly approved type of construction, although not quite of the high standard of the rigid conduit. It is made of steel strips wound spirally to form a tube with the edges of the strips so interlocked that considerable flexibility of the tubing is permitted. It comes in coil lengths ranging from 50 to 250 feet, depending upon the size, and is made from five-sixteenths of an inch to two and one-half inches inside dimension. One very popular make is called *Greenfield flexible* conduit. It may be joined by connectors that clamp the ends of two pieces into one continuous length. Other types of connectors may be employed to connect flexible to rigid conduit. The flexible conduit must be continuous from outlet to outlet and is attached to the outlet boxes by means of a collar that clamps a threaded end like a rigid conduit to the Greenfield. This end may be held to the outlet box by lock nuts. The wire used in such a flexible system, as in the rigid system, must be rubber covered. When bends are made they should be held secure by pipe straps (bands of metal) so that when "pulling in" the wire

these bends will not buckle and thereby make the pulling-in process almost impossible. This type of construction may be employed for concealed work, in either unfinished or finished buildings. Of course, the installation of a rigid system in a finished build-

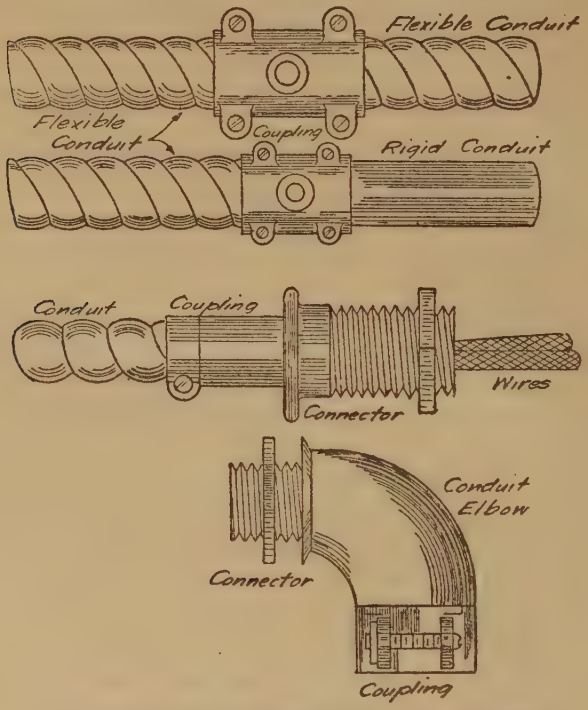


FIG. 148.—CONDUIT FITTINGS AND CONNECTORS

ing means a difficult and expensive undertaking; but the flexible conduit may be fished around through the partitions and under floors with a minimum of removal of the floor boards. Figure 148 shows some of the fittings used in connection with this type of conduit and also illustrates how they are employed.

The third system, which is used extensively, is the so-called *armored cable.* It is a flexible conduit, constructed directly over the wire with its insulation medium. It comes in single conductors made from sizes number 14 to number 1 (Brown & Sharpe) gauge wire; also in two conductor cables ranging in sizes from number 14 to number 4, and in three conductor cables in sizes from number 14 to number 6. The contractor called it BX cable from the trade

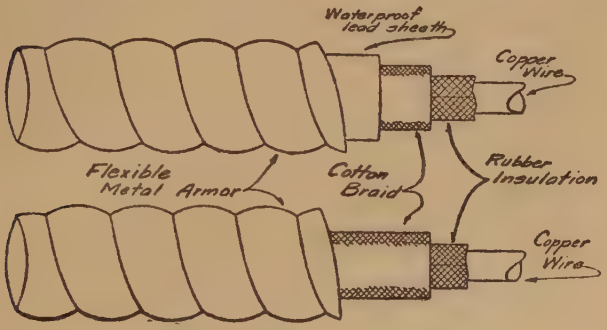


FIG. 149.—TYPES OF ARMORED CABLE

name of one of the most common makes. Some of this armored cable is built with a lead sheath placed directly over the wire with its necessary rubber insulation and then the flexible conduit over all. Such cable is called "BXL" cable meaning lead-covered BX cable. It is highly approved for damp locations, and is also directly installed in a concrete setting. Figure 149 shows such cables with their layers of insulation. These types of cable cannot be joined by couplings because of the wire connections and, therefore, the Underwriters' rules demand that the cable be continuous from outlet box to outlet box. It may be held into the outlet boxes by means

of clamps. Such construction is readily fished through finished buildings and is more readily accomplished than is the Greenfield type, since for the same size wire the BX is smaller in diameter than the Greenfield. Then, too, when the BX has been fished through, the wire is ready for connection.

Molding is a form of construction which is used entirely for exposed wiring. It is unsightly but does render a cheap construction that is often necessary where economy is of first importance. There are two forms of molding; one is metal and the other wood. The metal molding is permitted in most places, but wooden molding is not in good repute in general and many city ordinances prohibit its use at all, although the Underwriters do sanction it for use in certain places. The metal molding consists of a backing in the form of a sheet-metal trough over which a cover of the same material may be snapped into place after the wires are installed in position. There are fittings for angles, receptacles and "T" connections in order to make possible a continuous metal circuit. The metal may be cut in any desired lengths by a hacksaw or bent if the cover is on. The molding backing is screwed into place by the use of wood screws. Wherever the molding passes through a ceiling, it must be protected by first installing pipe through which it may be passed. If the molding is to be put through a wall, no pipe is required provided the wall is not subjected to moisture and furthermore that the molding is continuous through the partition without any joints. The metal molding must be thoroughly grounded as in the preceding case of the rigid and flexible conduit systems. These moldings are intended only

for small branch circuits and are made to hold only four number 14 wires.

Wooden molding is made, however, for both small and very large wires. It is made with either two or three grooves, for two or three wires respectively. It can be used only for exposed work, is not allowed in damp places or for circuits having higher than 300 volts. It is used oftentimes for wiring old buildings where it is placed on the ceilings, flexible conduit or other types being used in the walls. Rubber-insulated wire must be employed in wood molding. Wherever wires in exposed wooden molding work pass through floors, a conduit or porcelain tube must be installed and a wooden or metallic box placed around it to protect it from mechanical injury.

The cheapest form of electric wiring that is used for concealed work is called the *knob and tube system.* It has been used to a great extent in the wiring of moderate-priced houses. In the more progressive communities, it is becoming an obsolete form, however, although it is still quite extensively used. The porcelain knobs are employed to support the wire from contact with the surface over which it is wired. Tubes are used for general protection and wherever the wires pass through the walls or any other obstruction. There is also a tubing of a flexible nature made up of first a layer of canvas, then waterproof compound, over which is wound cord, then another layer of cotton-woven braid of waterproof compound. This tubing is commonly called *circular loom.* It is used for protection to the wire and serves as additional insulation, being used especially where taps are taken to an outlet to protect the wires as they pass into the outlet box. Figure

150 shows a piece of knob and tube wiring which indicates the protection at an outlet and in passing through a floor. The extra porcelains are required at the floor line to protect the wires against pieces of falling plaster during construction. Sometimes, when finished buildings are wired, circular loom is slipped over the wires for protection, but only the

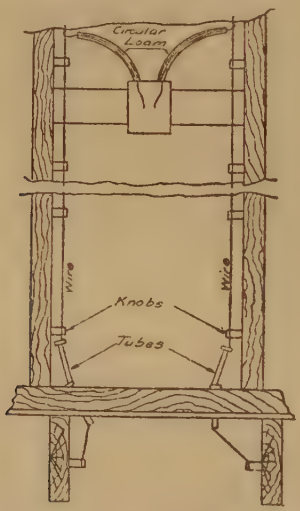


FIG. 150.—KNOB AND TUBE WIRING INSTALLATION

wires themselves can be conveniently placed on knobs. Of course, in new buildings, while the construction is in progress, it is quite a simple matter to locate the wires with the knob support. The wires should be held out at least one inch from the surface. Where wires cross each other, the wire nearer the surface should have a porcelain protection from the one crossing it.

Obviously, the wiring of a building which is under construction is relatively simple. The circuits may

be located as desired without constructional difficulty and regardless of whether the system is rigid or flexible conduit, armored cable, or knob and tube work concealed. Of course the great majority of wiring now must be concealed. Only in shops for rough work and in general unfinished-looking establishments is the open wiring tolerated. In the case of wiring old or finished buildings, however, ingenuity is required as well as a general knowledge of types of architecture and construction. Let us start with the service wires leading into the house. These wires in rural communities will lead to the house by a bracket support and glass insulator where the wires will enter a conduit and drop down for entrance into the basement. A drip loop is always allowed just where the wire enters the pot head of the conduit, in order to permit moisture to collect and drop off rather than run down the wire inside of the conduit. Conduit fittings are employed at the angles so that a continuous protected circuit may lead directly into the basement. Sometimes the wires are led from the bracket supports directly into the attic.

Figure 151 shows an entrance made to an attic and one made to a cellar. For underground transmission the entrance will, of course, be in the basement. In any event, however, the service board is placed as near as possible to the entrance point and the wires are run directly into a fuse block and main switch. The meter is next "connected in" to record the amount of energy consumed. From the meter the live wires are run into the distribution blocks from which the individual circuits radiate through the house, each being protected by a set of fuses. A branch circuit should not in general be over one

hundred feet in length. In ordinary houses, however, no such length circuit would be required. The wire is usually number 14 B. & S. gauge and not more than 660 watts per circuit is permitted. Sometimes, where the building is very large, branch mains, each protected by an individual switch and

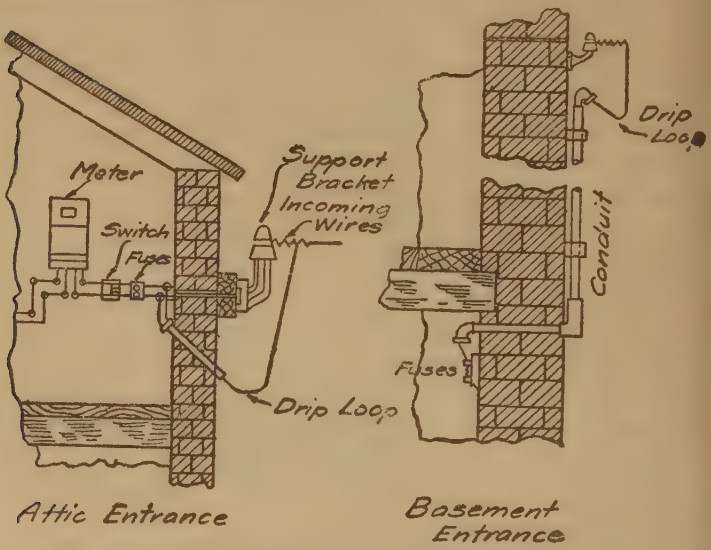


FIG. 151.—TYPES OF ENTRANCE OF ELECTRICAL ENERGY FOR HOUSE PURPOSES

individual fuses, are run to distribution centers located advantageously in the building. Each center is then supplied by a main. The sizes of the wire used in these cases must be calculated with care in order that the voltage drops incurred do not become prohibitive or noticeable at the lamp. In some of the very large installations, the size of wire required for such mains may be as large as 1,000,000 circular mils, which has an area of cross section

approximately six times that of a number 0000 B. & S. gauge wire.

Let us consider for our case that the wiring is to be done for a moderately sized home of finished construction. An analysis will be made of the procedure to be followed in installing, from the basement service board, a complete system throughout the house. The number of watts to be located on each circuit must be calculated to determine the number of circuits to radiate from the service board. For ordinary work number 14 wire would be suitable. This is the smallest size permitted for ordinary circuits. The armored BX cable is by all means advisable and would therefore be used for the wiring in the average installation. One circuit would be carried across the basement to the nearest point to that section of the house to be covered. Suppose the rooms to be lighted by this circuit are the kitchen, the pantry, the back porch, and the dining room, and that three wall lights are required in the kitchen, one in the pantry, one on the porch and a three-lamp chandelier over the dining room table, to be operated by an electrolier switch at the entrance from the kitchen, and four wall bracket lamps. The circuit would be run up through the wall separating the kitchen and dining room to the floor above which may be opened. A junction box would be placed there and would permit a tap to be made for a circuit to the kitchen, the pantry, and the porch lights. The porch light would in this case be controlled by a switch placed near the kitchen door. This circuit can be readily fished around by inserting a steel fish wire in the hole made for the outlet for the wall bracket light and working it up to the point where the end of the BX cable is located.

Then by attaching the cable to it, the BX may be pulled down to the desired outlet box and secured by an attachment. From outlet to outlet the wire is thus fished through. Then the fixture desired may be attached to this outlet box. Chain pull sockets are very desirable where individual control of each lamp is desired. In a similar manner the dining room wall lights may be wired by fishing around the BX cable from outlet to outlet. When a central or ceiling fixture is to be installed, the wire may be run out to the proper position by simply removing a couple of boards in the floor above. The wall switch for the control of such a center fixture must be connected in series with the lights of the fixture. The electrolier switch is so devised that, by successively snapping the switch, one, two, three, or more lamps may be lighted as desired. For dining room and for the central fixture in a large parlor or drawing room, such electrolier switches are convenient.

The problem of laying out a well-arranged scheme of lighting in the home is an art requiring much experience and expert training. Of all installations, that of the home should be given the most careful attention in order to secure through the illumination an atmosphere of rest, of harmony and of comfort. As explained in a preceding chapter on lighting, this may be done by judicious placing of the light units and by attention to the color scheme.

The drawing room and parlor should be equipped with portable units, such as floor or piano lamps and table lamps in order that the monotony of fixed conditions may be relieved as desired. The efforts of decorators and art designers is to create a fresh stimulation by ingenious devices of iridescent materials, illumination effects, and frequent rearrange-

ment. It is common experience with all that the energetic housewife freshens the room and effectively breaks the monotony by rearranging the furnishings of the bedroom, of the parlor and the living room. Many attractively furnished homes have been rendered commonplace and staid in appearance in the evening under the light of the stately central fixture which gives no opportunity to vary the lighting effects. The use of wall brackets judiciously placed in conjunction with the portable lamps produces a system whose flexibility permits of any degree of variation in the method that produces coziness and subdued beauty to the room. Occasionally a large room, used as a reception room or formal parlor, may well accommodate an artistic central fixture of more or less elaborate design depending upon the many possible conditions.

Too much emphasis cannot be placed upon home lighting both as a social factor and as a means for making the home intimately attractive and thereby supplying all that the word "home" conveys. Without moralizing, it may yet be said that "the lure of the gay lights" can in a large measure be established in the home, by our present illuminating possibilities. The designers of the clubroom and the cafe know the value of lighting systems and are using them successfully.

The dining room may be so illuminated that the table, the center of attraction, may be made "a thing of beauty and a joy forever," or it may be made so commonplace that all the supplementary art of the daintiest housewife will fail to produce a pleasing effect. The snow-white linen, the cut glass, the silver, the unobtrusive but dainty center bouquet and the well arranged dishes of viands constitute a

picture that falls short of its possibilities unless displayed in its proper setting—adequate and proper illumination.

The general room illumination should be relatively low, whereas the localized lighting by means of a central fixture over the table, should be more brilliant to display the center of attraction and to cause the important details, such as walls and pictures to form shadowy, soft and uncertain lines to serve as a background for the table proper. This effect in a small room may be effectively produced by a central fixture properly designed. An inverted bowl may be employed having a system of drop lights around its edge. The inverted bowl diffuses the light generally about the room, whereas the drop lights directly illuminate the table. The shade holders for the drops should be sufficiently deep to screen any glare from direct rays. Some inverted fixtures have for this purpose a center hole to afford direct light upon the table but diffused illumination elsewhere. In large rooms in addition to such a central fixture, the general illumination may be augmented by well placed wall brackets having units of small candle power and protected by silk screens or shades. Very attractive and desirable dining room illumination may be procured through care and consideration on the part of the contractor in cooperation with the owner.

The reception hall is a vantage point in most homes where a lasting impression may be quickly given to a caller. Of course, the architectural considerations modify the design of the lighting to such an extent that practically no general type can be given. There are a great variety of possibilities, however, which can be studied to supply the in-

dividual tastes. On the dark evening, the reception in a spacious foyer hall may be made most cordial and cheerful through light of an adequate amount and of a proper color scheme. Orange shades have been found to give a most pleasing illumination, but the units should not be prominently in evidence. Sometimes cove lighting, where the light comes by reflection from concealed pockets near the ceiling or from pillars at the stairway, may give beautiful results. The hallway illumination should, in any event, be controlled from at least one downstair position naturally near the entrance from the street and one position at the head of the stairs. Such conveniences add practically nothing to the cost of the installation but mean considerable in the flexibility of control of the system.

The lighting requirements of kitchens, closets, pantries, piazzas, and basements are so general that it is necessary only to remind one that an adequate amount of light is essential and that the location of the units should be judiciously chosen so that their purpose will be fully accomplished.

The bedroom or boudoir makes a demand on the art of illumination that varies from the luxurious equipment found in the most elaborate mansions to that of the one fixture simplicity of the most modest home. Here wall brackets with appropriate shades of silk form a very attractive fixture for general lighting. More elaborate requirements may demand reading lamps from floor plugs and small table lamps for use at the bedside. The bathroom should have a wall bracket unit placed at both sides of the mirror over the wash bowl. Such light shines into and illuminates the face directly. This arrangement is effectively appreciated by the men of the family

since it gives the necessary lighting for satisfactory shaving.

Illumination is thus an art which should be intrusted to one of experience and artistic judgment in order that the design and layout of the system may bring out to the greatest extent the pleasing features of the architecture and furnishings of the various rooms of the house. The illuminating engineer must work in conjunction with the architect and decorators in order not to defeat the harmony of the entire scheme of things. The use of table and other portable lamps must be anticipated, therefore, and the necessary baseboard and floor outlets provided. These constitute also suitable outlets for heating devices and for vacuum cleaners and other electrical attachments and conveniences. The general practice then, of installing baseboard outlets is one to be encouraged since it affords means for real comfort and service.

CHAPTER IV

ELECTRICAL APPLIANCES IN THE HOME

FOR many years past, the thought, the energy, and the study of the great engineers of our land have been directed largely toward the development of labor-saving machinery for the great industries that have sprung up on all sides. While many of these have had a wholesome and thrifty infancy, the realization of their maturity and permanency was dependent solely upon the perfection of automatic machinery to replace or reduce to a minimum the need for human labor. Such an evolution is not only normal but highly desirable since the labor that is released through abolishing the old-fashioned methods is made available elsewhere, where it is more urgently needed for the extension of the industry and for the operation of the automatic machinery. In general, however, labor resents this introduction of new methods and opposes strenuously any factors that favor increased efficiency at the expense of man power.

Notwithstanding the remarkable progress that has been accomplished in this industrial world through the ability and genius of the engineers, the average home, until recently, has received but scant consideration as far as labor-saving devices are concerned. Recently, however, a great impetus has been given such a development through the welcome

accorded by housewives and home workers to the efforts of manufacturers of household equipment.

At first the inertia against the universal adoption of devices of any kind to lighten the arduous tasks of the home was due to many fundamental causes. The supply of electrical energy was not a most certain factor and its prohibitive cost kept it beyond the reach of the middle class. Then, as the supply became quite stable, and costs were reduced to within the reach of the great majority, thereby establishing electric lighting as a possible convenience and household necessity, the electric motor, in the then present state of development, was found to be inadequate to meet the new demands placed upon it. For practically every application of the small fractional horsepower motor new specifications were imposed that required additional study and subsequent renovation of design. More significant, however, was the abundance of labor. Servant help was most plentiful at a relatively low wage. But as time went on, the servant question became such a vital problem and was such a constant source of annoyance to the peaceful pursuits of the household activities, that any means to alleviate the situation were welcomed with enthusiasm and quickly adopted.

Little do we appreciate the tremendous amount of money invested in the construction and efficient operation of the central plants for electrical generation. There are in our land over 5,500 plants that supply the surrounding communities with energy for operating labor-saving devices. These represent a capitalization of about three billion dollars. An idea of the enormous capacity of some of the larger types of these plants may be gained from the fact that they generate sufficient electrical energy to

supply the power requirements for the operation of eight of the largest and most modern battleships afloat. Little can we realize the vast supply of energy available until we make a comparison of the present extensive application with that of an earlier period.

It has already been stated and considered at length, in a preceding chapter, that of all household demands for conveniences none could ever equal that of electric illumination. It has long since passed from the lists of luxury to those of necessity. Indeed, the home seems oddly antiquated where gas and oil lamps still remain as a source of light. The twentieth century has ushered in an era in which the dreams of luxury and the air castles of the more modern Aladdin have been materialized even in the most humble home. Especially is this true in the land of the Stars and Stripes. The American is progressive to a fault. He has a thrift peculiarly individual. He works hard and with a will to acquire means for the rapid introduction and establishment in his home of all the available labor-saving and comfort-giving devices. In New York City alone more telephones are in use than in any entire European nation. Long lists of similar comparison could be cited that would sound startling simply because we do not stop long enough to compare our standing with that of the other countries.

It is a most natural condition and yet a quite unfortunate one, that we so quickly lose our recognition and appreciation of the wonders that surround us on every hand. A few years ago, possibly thirty years or so, the sight of a street car caused much comment and praise, and it was but seldom that,

when one passed, it was not looked upon with a feeling of pride that we possessed such ingenious transportation facilities. Now, the street car is so commonplace that even the five-year-old child never pauses in his play to look at one and instead of praise the adult now has only words of denunciation for its poor service, slow progress, and general inconvenience. At the very period when the electric car was becoming commonplace in our experiences, the thought of a heavier-than-air flying machine was scoffed at as the product of an unbalanced mind. Consider the multitude of machines now soaring in the heavens with altitude records thousands of feet higher than the most lofty mountain peak, and with speed records that seem incredible. So surely established is the flight of these machines that Uncle Sam has relegated to their care the transportation of his most important mail.

On every hand, the convenience of the past is a necessity of the present, and we become conscious of their conveniences on occasions when through their temporary absence we must resort to the methods of the times of our forefathers. We still hear, on occasions, the remarks of the sleeper who glories in the "good old times" of his boyhood, or even more remote periods, and has not yet awakened to the advanced conditions of his own time. Such an individual is certainly missing the best that there is, the sense of progress and the desire to keep abreast of the times. We have but to consider the agency that brings relief, for instance, on the hot summer day when the temperature is up to ninety and the humidity far above normal, to realize the great benefit afforded by a single mechanical device—the electric fan. The eight-inch electric fan, which costs

little more than an electric light to operate, serves to carry away the stagnant air, and thus to refresh the atmosphere. The fan was one of the first household conveniences to follow electric lighting. Then came the heating appliances, such as flatirons and electric grills. These are now found in nearly every home. All of the aforementioned heating devices operate on the principle that an electric current passing through a conductor creates heat under certain conditions and that in such cases no motor or turning effort is required. Perhaps, of the heating devices, the flatiron above all has meant more to the housewife than the others. No longer does she have to slave in the hot kitchen on a hot day, using the irons heated from the stove, which constantly vary in temperature and thus make the accomplishment of satisfactory work difficult. With the electrically heated iron she may work in a cool outkitchen with an iron that has a uniform temperature and which is, therefore, capable of giving the best results.

The electric toasters, grills, chafing dishes, percolators, etc., find ready use in the home for preparing light meals directly at the table. Particularly are they convenient and serviceable for the preparation of breakfasts. Toast may be made as desired and the coffee prepared in a more delicious way by means of percolators than in the ordinary coffee pot. The grill may be employed for frying eggs, chops or bacon and the like. These operations may be done expeditiously at the table without noise or commotion and with a minimum expenditure of heat.

The many labor-saving devices now found in the home, and which require the use of motor drive, have

been developed slowly since the manufacturers of both the devices and the motors have been slow in cooperating. Such apparatus as washing machines, ironers, mangles, or vacuum cleaners, dishwashers, refrigeration machines, water pumps, exhaust fans, blowers, thermostats for automatic damper regulation and control of coal heaters, hot water heaters, gas and oil burners, electric vibrators and massage machines, and hair dryers have gradually come into popular use, however, and are daily enlarging their field of application as they are becoming more efficient. The differentiating features of these machines will be described with special attention to the precautions to be observed in their use.

WASHING MACHINE: There are four distinct types of electric washing machines, known respectively as the *Dolly type, cylinder type, oscillating tub type* and the *vacuum cup type.* These are all driven by a motor and most of them have a wringer attached to operate in conjunction with the washer from the same motor drive. The motor of these machines must have a high torque at low speed, a condition which calls for special design. One-sixth horsepower, however, has been found to be ample for handling the requirements of the washing machine and the wringer. Such a motor has entailed much study to secure a design that would combine the qualities of power, speed, acceleration, and light weight. The insulation must be especially well designed since the parts are all metal, and a ground on the frame would be quite disconcerting to the operator in the event of a shock.

The various types of washing machines are differentiated primarily by the method employed for the agitation of the water in reference to the clothes.

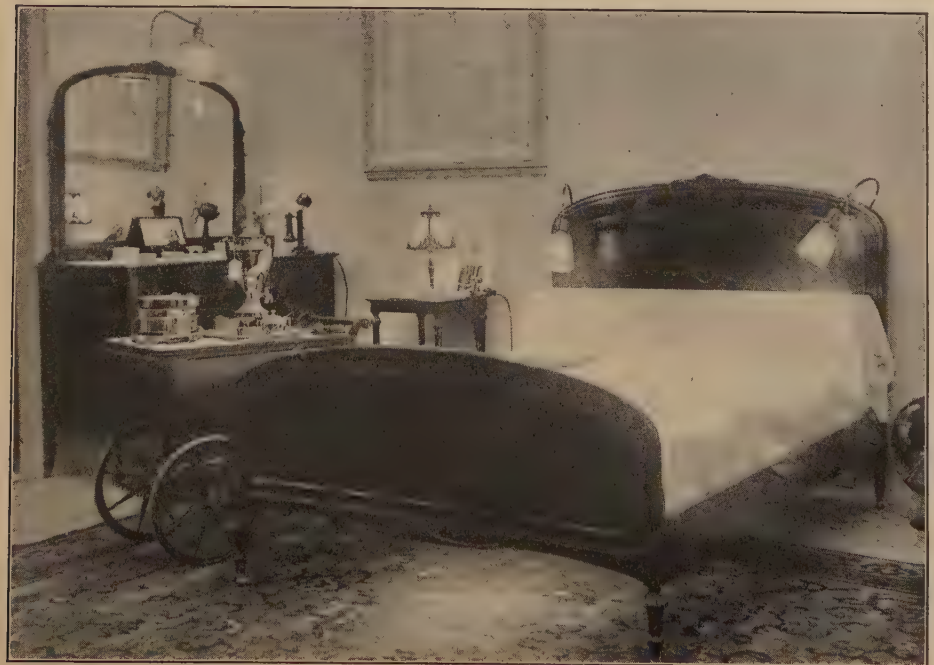
In the Dolly type, the clothes are swished around through the water in a conical shaped tub in a way quite similar to that employed in the former hand-operated washers. These electrically driven machines are simply an outgrowth of this type. The cylinder type consists of a tub of semicylindrical shape within which revolves a perforated cylinder having projections within it. The clothes to be washed are placed within this inner cylinder, and as it turns the clothes are lifted by the projections and splashed into the suds of the water. A gear arrangement connects the motor from first the drive of the washer to the drive of the wringer. These electric wringers are quite similar to the hand wringers in common use, except that they are driven by motor power. The safety devices designed to protect the fingers of the operator from being crushed in the wringers are still partially unsatisfactory, and, as is the case in any machines, these too must be operated with due precaution.

The third type of washer employs the oscillating tub scheme. Here an elliptical-shaped tub is so mounted that it swings to and fro with a sort of cradle motion which imparts in turn a figure 8 motion to the water. As a result the water is forced violently through the clothes and thereby produces the required cleaning process.

The vacuum cup type of washer employs inverted cups that play up and down with a slow rotational movement which serves to give agitation to the water and also to draw it through the clothes. Some of them actually employ a vacuum in the cup while others are agitators, pure and simple. One type of machine that works on this principle employs a dryer far superior to the wringer and should by its

merits win general favor because of safety in operation, preservation of fabric and of buttons. The driver is of the centrifugal type as is used in all steam laundries. This type of washer is a cylindrical tub open at the top. Inside of this is a perforated cylinder also open at the top and into which the clothes are placed. The cups play up and down agitating the water and slowly revolving the clothes. The dirt, as it is separated, precipitates below, a desirable action since it no longer comes in contact with the clothes. When the washing process is completed, the inner cylinder is lifted up clear of the water surface by means of a foot lever, and a shaft changes the power over to rotating this cylinder at a high rate of speed. The water retained in the wet clothes is hurled out by centrifugal force through the tiny holes in the side of the cylinder, and in four minutes the clothes may be made as dry as the ordinary wringer would dry them, or in ten minutes sufficiently dry for immediate ironing. Of course, one prefers to dry them in the air to secure the beneficial effect of bleaching and purifying by the sunlight. In the event of rain or in the winter, however, they may be dried indoors by this centrifugal process in a few minutes. The most dainty fabrics may thus be dried with no fear of destruction and buttons cannot possibly be torn from the cloth, as is the constant danger with the roller type wringer.

The washing machine has proved to be the greatest friend to the housewife. She may fill the tub by hose with hot water, add soap and then place therein the clothes. A turn of a switch starts the first operation and leaves her free to prepare and enjoy her breakfast. The clothes may then be wrung out, rinsed, and blued immediately after



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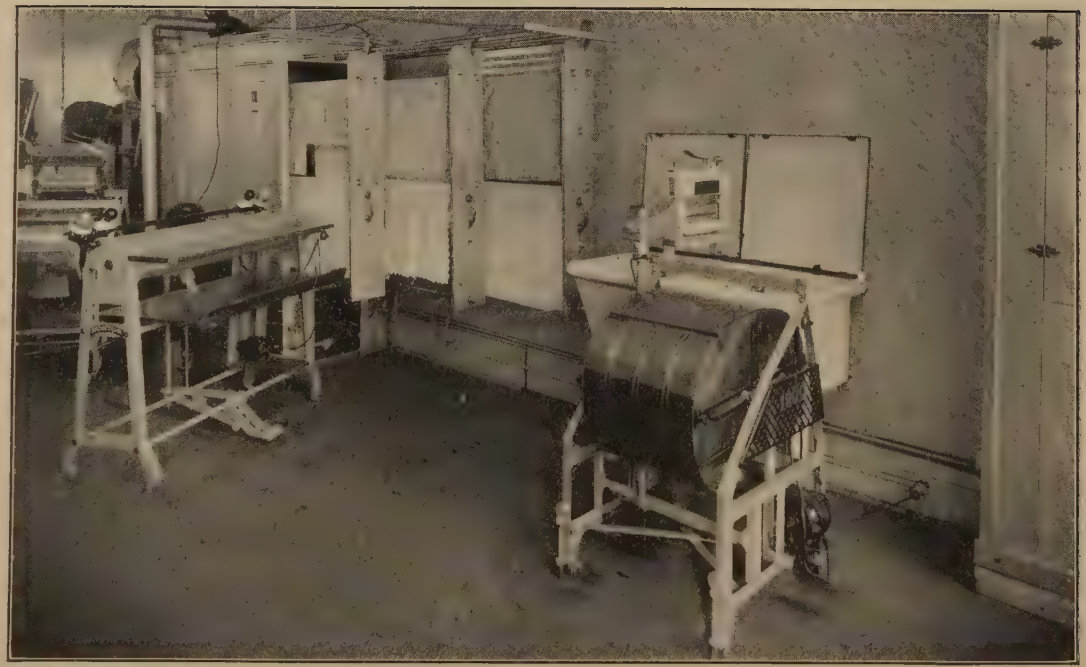
USEFUL ELECTRICAL APPLIANCES FOR THE HOME



ELECTRICAL EQUIPMENT FOR A LAUNDRY

breakfast. If the wash is of moderate size, it may be completed by one process. If, however, it is large, it may require a second rotative operation. While other work is being done about the house, the washing can proceed without attention. Instead of the "blue Monday" for the household in anticipation of disruption of the usually smooth routine by the arrival of the washlady with her demands for constant refreshments, the day set aside for washing is by many housewives now looked forward to with a certain zest. This is expressed in doing the washing themselves with a washing machine as their sole companion. The cost of operation of the washer is an item not even worthy of consideration since one may be operated for a whole hour and cost only two cents or the price of one postage stamp. The entire washing which would require all morning by the hand process may be done in from one to two hours by machine, and the actual time required of the operator need be only a small fraction of this period.

Thus, for example, to show the efficiency of the electrical household, the washer may be started before breakfast to run during the twenty minutes required for the breakfast. This may be prepared on the electrical cooking devices without the lady of the house stirring from her chair. Immediately upon completion of breakfast, she may place all the soiled dishes into the electric dishwasher, which will operate while she is attending to the rinsing and bluing of the clothes just washed. Then, if another wash is to be run through, it can be started. The dishes, meanwhile, have become ready for scalding, a process which dries them and sterilizes them thoroughly. While the washing is progressing still fur-

ther, the lady may run over some of the rooms with the vacuum cleaner and behold, in two hours from the start, many tasks have been accomplished almost simultaneously with little expenditure of physical energy. The fear of the drudgery of the days of old has been replaced by the anticipation of "play mornings" of efficient but comparatively light work.

ELECTRIC MANGLE. The device which really should accompany every washer to remove entirely the dread of the family wash, is the ironing machine. This device is designed to accomplish quickly and with no tedious labor, the work which the electric iron greatly facilitates. All flat pieces may be fed into this ironer, and in only a few minutes the heavy part of the ironing has been completed. Towels, handkerchiefs, sheets, pillow slips, blankets, counterpanes, tablecloths, napkins, collars, and cuffs are readily handled by an ironing machine. These ironers are sometimes called mangles. They are used entirely in the ironing of flat work in the laundries. They operate as follows: a semicylindrical stationary shoe has a revolving cylinder that fits its curvature. This steel stationary shoe has a highy polished surface like a flatiron and may be heated from within by a gas or electric heater. The revolving cylinder is covered with thicknesses of hair or felt with a sheeting tightly stretched over all. This ironing shoe is so arranged that it can be tightly pressed to the revolving cylinder by means of a lever. The drum is rotated by a motor whose speed can be controlled to suit conditions. The temperature of the ironer may, therefore, be maintained at a constant value and most satisfactory work accomplished. The material is fed in between the revolving drum

and the shoe where the pressure is easily regulated to suit the materials. For example, napkins may be run through flat, then folded as desired and run through for creasing. What little work the ironing machine will not take, may be pressed out later by the electric iron.

VACUUM SWEEPER. The days of the sweeper and broom are numbered as far, at least, as household work is concerned. The spring and fall house cleaning has been assisted now for many years by the wagon vacuum cleaner machines which may have been seen going from house to house. These machines have served a fine purpose, but are being replaced by the long-delayed individual household size cleaners which are now being manufactured in enormous numbers. The time will come when the use of the broom will be looked upon with the same critical and condemning eyes that have caused the old type open garbage can at the back door to assume the shape of a clean galvanized bucket with a well-fitting cover. Instead of stirring up the dust by brushing the carpets and floors and filling the atmosphere with carriers of disease and clouds of germs, the vacuum cleaner sucks up the dust from the floor and carpet, depositing it in a bag for that purpose. Threads, lint and ravelings which cannot easily be removed by sweeping or by sweepers readily yield to the suction of the vacuum sweeper.

The principal parts of such a sweeper are the motor, the fan and housing, the nozzle, and the dust bag. Practically all the many machines on the market to-day have similar construction, differing only in details for patent protection. The motors must revolve at an exceptionally high speed in order to produce the suction necessary. These speeds

run from 8,000 to 9,000 revolutions per minute. Further, motors are now being built of rugged construction, light in weight, and durable for many years of service. They certainly perform the operations of sweeping in a most sanitary manner and they are especially desirable for cleaning upholstery, tapestry, walls, and bedding. In purchasing a vacuum sweeper, care should be given to procure one employing the rotating brush placed just in front of the nozzle. This proves very effective in stirring up the dust and in rolling up the ravelings into a better form for the nozzle to take up. The cost of these sweepers, due to the keen competition, has come down within the reach of every home, where the desire for one prompts its purchase.

ELECTRIC DISHWASHER. The progress in electric dishwashing machines has by no means kept pace with the development of other types of household devices. They are made and operate in two different styles—one the splash system and the other the centrifugal system. The former employs a propeller, and the latter a centrifugal pump for the agitation of the water in order to shoot it over the dishes which are contained in a wire basket held within a cylinder. A motor is used to drive the propeller or pump. Each dish receives a direct spray or splash and is thus both uniformly and thoroughly cleaned. The drying is accomplished by pouring extremely hot water over the dishes in the tray. This action sterilizes and dries them by evaporization. The great field open to a successful washer should be a sufficient stimulus to inventors to devise a more perfect machine.

SEWING MACHINES are now being operated by motor drive. The manufacturers of sewing ma-

chines have been slow and reluctant to apply this type of drive; but now they may be found in two general styles, one where the motor is applied by friction drive to a machine already in use, and the other where it is built as a part of the construction of the machine. A small series motor is used with a rheostatic control for varying the speed. Motor-driven machines can operate as high as 600 stitches per minute. This is fully three times faster than for foot operation. Skill in operation, when attained, permits high production and efficiency in the work. Yet, even with the high speed, the machine may be stopped almost instantly.

MECHANICAL REFRIGERATION is receiving more and more attention as the cost of ice increases from year to year. Of course, refrigeration systems have been for years applied in cooling markets, storage houses, skating rinks and the like. For domestic purposes, however, the introduction of such systems presents many difficult requirements. The machines must be foolproof and absolutely noiseless, and since they may start and stop at any period of the twenty-four hours, they must be highly reliable, and have automatic control. Further, they must not be too costly to install, and the cost of operation must not exceed the cost of ice for the same purpose.

One of the systems employed in the larger plants depends upon the direct expansion method of cooling, whereas a second system uses the brine method. Various substances are employed for the cooling media, such as carbon dioxide, and ammonia gases. These are compressed to very high pressures in a tank and when allowed to expand through a nozzle, absorb heat from the surrounding air, thereby affecting the refrigeration process. This condensed gas

may then be repumped and recompressed again ready for use. Such a system uses the direct expansion principle. In the brine system, which of the two is employed more extensively in the larger plants (in markets and storage warehouses) the direct expansion is utilized to cool the brine which in turn is circulated throughout the system. A small outfit may act similarly in cooling a built-in inclosure like a refrigerator or a portable outfit. When the temperature reaches a certain predetermined point the apparatus stops, but if a higher temperature limit is again reached, the apparatus automatically starts. For this automatic control a thermostatic switch is arranged to open and close the motor circuit.

EXHAUST FANS AND BLOWERS are being used to a small extent in kitchens and basements for refreshing by circulation the vitiated air or the odors of cooking. Blowers are also desirable to supply a forced draft to the furnace in severe winter weather. Blowing air over a radiator serves to carry the heated air away and thereby aids the more rapid heating of the room. The motors must be quiet in operation, dustproof, light, strong for their weight, and efficient. They are, of course, widely used in larger sizes in hotels, subways, and public buildings. Series motors are most desirable for such a type of drive since the load is constant and a large torque for relatively low current is produced.

WATER PUMPS are used to some extent in rural communities for storing up water. They usually pump the water into pressure tanks where an air cushion acts as a coiled-up spring. When the pressure accumulates to a certain value, the pump stops, but starts again when the pressure has fallen to a

minimum predetermined value. A one-horsepower motor is a suitable size for an ordinary set.

PHONOGRAPHS are being motor driven to some extent in the newer models. The manufacturers have not taken kindly to the idea; but demands for them have accelerated the supply. Some operate by replacing the spring winding crank by a motor, whereas others operate the turntable itself and are controlled by a governor just as is the spring motor.

ELECTRIC VIBRATORS. For skin treatment the electric vibrator and massager has found extensive service in barber shops, in hair dressing parlors, in doctors' offices and in recent years also quite extensively in the home. A small motor, through the medium of an eccentric, vibrates a cup or applicator very rapidly. For the purpose of drying hair, a hair drier consisting of a small motor-driven fan for driving warmed air through the hair and over the head serves to dry and aerate in a most beneficial manner.

AUTOMATIC HEAT REGULATORS are finding favor among heating experts and the public, since no subject so vitally touches the heart of the home at present as does the cost of each ton of coal that is reluctantly deposited in the basement. The control of the fire by automatic procedure conserves the coal supply to the very last pound. The system of heating may be hot water, steam, hot air, or a combination heater, or there may be a central heating plant. The outfit consists of a thermostat located in the rooms and made to connect to and control a motor on the heater. This motor in turn regulates the various dampers through gears and levers. When the temperature reaches the maximum value, the dampers are closed and remain so until the tem-

perature falls to a certain minimum value. These values of upper and lower limitation may be set to suit the conditions. That is, the range may be made, for instance, from 74 degrees to 67 degrees Fahrenheit. Or one may prefer to have it from 70 degrees to 65 degrees. It may thus be adjusted to any desired value by simply setting an indicator device. Frequently, one desires a time device which may open the dampers and raise the temperature to a predetermined value at a certain period of the day. Perhaps, for example, it is desired to have the drafts opened at 6 A. M. by the time regulator with a maximum temperature control at 70 degrees, so that when one arises the house will be well warmed and the fire burning brightly after the night's banking. The operation, of course, must be reliable and quiet. There are many such regulators on the market which more or less satisfactorily meet the requirements of such a system.

ELECTRIC RANGES. Aside from the general heating units employed in small cooking devices for the table, which certainly are valuable and are serving an increasing demand, the kitchen range is an indispensable adjunct to the home. Rather than employ a coal range, which must be kept going all day and perhaps even at night, since the frequent starting of a coal fire is most uneconomical and a constant source of annoyance and extra labor, the electric range serves the purpose of cooking and is drawing energy only when actually in use. The heat may be shut off or turned on as desired and it may be controlled in three different heats—low, medium and high—by the simple manipulation of a switch. These ranges may be purchased in small or large sizes with one, two, or more holes or hot plates

as desired, and having ovens, broilers, and warming ovens.

Of course, the feasibility of the employment of an electric range immediately brings up the subject of the cost of operation and the comparison with gas and coal. More than 4,000 electric stations have published cooking rates to encourage the use of these utilities as they form a desirable load for any plant. These rates range from three cents to five cents per kilowatt hour. At the latter rate, electric cooking may successfully compete in price with artificial gas at the prevailing rates. In regard to the quality of the cooking it is undeniably superior to that of either gas or coal range. No form of energy conversion from one form to another is more economical and complete than is the electric energy into heat energy. The percentage of conversion runs better than 98 per cent. In supplying energy at a special rate for electric cooking, a separate meter is used on a separate circuit.

The future of the electrical appliances for domestic use is a most bright and encouraging one. At present only from six to seven millions of homes are invaded at all by the electrical conveniences. There are yet about thirteen millions of homes which will surely yield to this increasing army of enthusiasts for the more efficient, convenient, and hygienic way of accomplishing the household duties. The process of education starts slowly and with great inertia, but when once under headway carries itself along with increasing momentum. The per capita income in this country is higher than ever before, and is continually increasing as the wealth of the nation increases through the new enterprises, expansion of business and industry and surely the future growth

and expansion of the use of electricity in the home will at least keep pace if not actually outstrip this general growth of wealth. Then, too, many apparently outside factors enter into the question and exert a powerful influence in determining certain growths. For example, since the war, the servant question has become so acute that many homes have preferred to install electrical conveniences and so do away in part or entirely with hired help. The independence of washwomen has contributed emphatically to the increased sales of washing machines and laundry equipment. In fact, it seems as though the exigencies of the times has given the impetus to the use of household equipment.

CHAPTER V

ELECTRIC COMMUNICATION—TELEGRAPHY, TELEPHONY, AND RADIO

AMONG the many conveniences that have now become necessities rather than luxuries, a prominent place must be given to the telephone and the telegraph for transmission of messages of a different character. These two devices are often designated under the general expression *means for electric communication.* The etymological meaning of the word *telephone* is *talking at a distance* while that of the term *telegraph* is *writing at a distance.* The telephone will be considered first.

In our present age, no man would for a moment consider operating a business organization without having a telephone installed in each office. As a result, a network of telephone lines now covers the entire surface of our great land. The city of San Francisco is in as close proximity to New York City for conversational purposes as is Philadelphia or Boston. The great centers of industry in the United States are securely tied together by the instantaneous transmission of speech from one place to another. The operators of the central offices are the weavers of business connections. Thousands of messages are sent daily across the vast distances intervening the extreme points of our land. Only within the past six years, however, has the Pacific Coast been brought side by side with the Atlantic

in regard to the transmission of speech. Consequently the man in Los Angeles may now be heard as clearly in Boston as can the suburban subscriber be heard in the near-by city.

The United States Supreme Court after a bitter struggle of litigation favored Alexander Graham Bell with the invention of the telephone in 1876, although it appears that a German by the name of Reis had given the name, *the telephone,* to a device for tranmitting speech as early as 1860. The future field of usefulness was readily conceived, and immediately hundreds of independent companies were formed and a more or less complete telephone system was installed in the larger towns and cities. The growth since then has been phenomenal, and has led to the merging of the majority of the small companies into the one great syndicate, the Bell System, which has introduced a complete and connected network that could not otherwise have been so efficiently established. A large corps of the ablest engineers have for years been at work constantly improving the system and the apparatus. The latest result toward increased efficiency has been the perfecting of automatic telephony whereby the central operator will be replaced by automatic machines that will switch the calling party to the party desired with most incredible speed. Such a system has already been installed by the Bell Company in Kansas City, and is now under construction in New York City. A separate company has for years operated a most successful system through the Middle West territory and the gain in its popularity has aroused the most acute competition. The time is not far distant before the slow, uncertain, careless manipulation of the central operators will be re-

placed completely by the lightning speed automatic method.

The telephone service may be divided into two general classes: the public service and the private service. The first has the exchange and toll systems and is not a local institution. The private system, however, is of this type and may be for train and load dispatching, line patrol, intercommunication, and general communication. The public system is, of course, operated for commercial profit and the calls have a fixed tariff or rate, and may be broadly defined as a common carrier of communication.

The features of importance and of general interest are the parts of a complete telephone system and the manner in which they operate and function with each other in order to accomplish the marvelous results that they do. The principal parts of a telephone system are: the transmitter and receiver in the subscriber's control, the lines, and the central office with its equipment. These various parts will be considered in detail as to their working features and relations. Only the most commonly used and up-to-date instruments will be considered since the space is insufficient to give detailed account of the historical development.

The transmitter is the device that acts as the interpreter for the electrical system, so to speak. It receives the audible sounds which we call *speech*, and converts them into *electrical impulses* that are conveyed with lightning speed along the connecting lines to the receiver at the far end of the line through the intermediary of the central office, where interconnection of one subscriber with another is accomplished. The air waves that accompany speech and

which vary in quality, intensity, and pitch impinge upon a sensitive diaphragm of the transmitter and cause it to vibrate in synchronism with the air disturbances. This diaphragm constitutes a part of an electric circuit in such a way that the current which flows through the line is varied in intensity, in frequency, and in wave-shape in accordance with the characteristics of the impressed sounds. These current impulses in the line travel to the receiver at the end of the line where an inverse operation of the transmitter converts them into audible sound. The device at this end is called a *receiver*. In long interconnecting lines, the electrical impulses or waves in traversing the intervening distance suffer loss of intensity and change in wave form, conditions which mean diminution in the loudness and lack of clearness respectively in the reproduced speech. Telephone engineers have tried to overcome these difficulties in transmission so that long-distance speech may have as near as possible the same pitch, quality and intensity as at the transmitting end. Sometimes the voice currents, as they are called, are transmitted through the lines as alternating currents only, and in other systems these alternations are superimposed on a continuous current. A typical system layout of the type where no current flows in the main lines except when the speech waves are actually operating is shown in Figure 152. To simplify the diagram the central office is not shown, but the action of the transmitter and receiver will be considered in detail. Such a system is called the *magneto bridging telephone system*. It was in vogue before the more recent *common battery type*. The name *bridging set* was given to this type since all parts, the transmitter, receiver, generator and ringer

were directly across the line—that is bridging or shunting it. The operation of such a system is as follows: When subscriber "A" desires conversation with subscriber "B," he turns the handle of the generator, which is a simple alternator, and causes a signal to drop at the central office. The operator

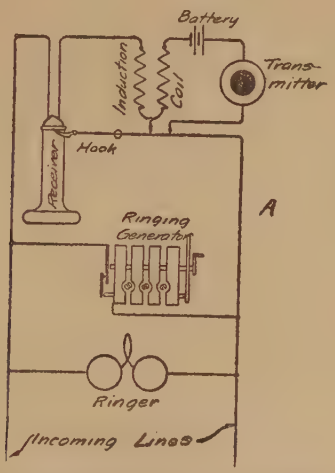


FIG. 152.—MAGNETO TYPE SUBSCRIBER'S TELEPHONE EQUIPMENT

places a *plug*, one end of a *cord circuit*, into the terminals of that line called a *spring jack* and by that means may, by depressing the *listening key*, talk to subscriber "A" and ask the number desired. Then the operator will plug the other end of the same cord circuit into the jack of the number called for and by depressing the *ringing key* cause the ringer of subscriber "B" to sound, and metallic connection to be established between "A" and "B."

When the subscribers are talking, of course, the receivers have been removed from the hooks, which

spring up and cause connections at the two arrow points, as shown in Figure 152. As this is accomplished, direct current flows from the battery through the transmitter, a part of the receiver hook, and the primary coil of an induction coil or transformer. No current at all flows in the secondary circuit since the primary current is of constant, uniform value. Now, by talking into the transmitter, the variation of the diaphragm due to the impinging air waves cause the resistance of this primary circuit to change, which in turn causes variation in the primary current proportional in intensity to the speech waves. Whenever variations in the magnetic effect of one circuit affect a second adjacent circuit, an alternating current is induced in this second circuit. Consequently, then, an alternating current is caused to flow in the secondary circuit, connecting the lines and the receiver of the other subscriber.

The transmitter is composed of simply a mouthpiece with the diaphragm behind it. Between this diaphragm and a solid back is a space which is filled with finely divided carbon granules. The primary electrical circuit is completed through this solid back of carbon granules and the diaphragm. As the diaphragm vibrates, the carbon granules are more or less tightly compressed, a condition which varies the resistance of the circuit and consequently the current that flows.

The receiver performs the reverse operation of the transmitter—that is, of receiving electrical impulses and interpreting them as audible sounds identical to those spoken into the distant mouthpiece. The simplified arrangement of parts is shown in Figure 153. It is seen to be comprised of a double bar

permanent magnet, a diaphragm of thin magnetic metal and a coil mounted on the combined magnetic pole. The influence of the permanent magnet holds the diaphragm in normal tension and as the alternating electrical impulses from the line pass through the coil which augments or diminishes the pull in

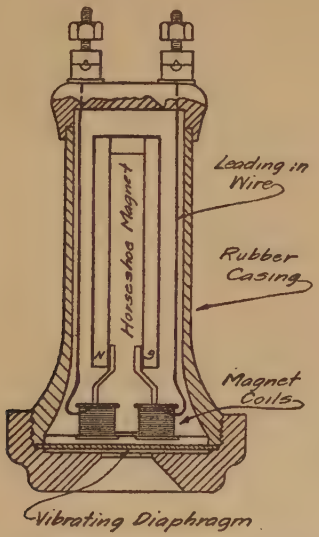


FIG. 153.—SECTIONAL VIEW OF A TELEPHONE RECEIVER

accordance with the line impulses, the diaphragm vibrates practically in synchronism with the incoming variations and causes air waves to set up audible sounds.

At the central office of this magneto system, the lines of each subscriber terminate in a jack, which is a receptacle for the plug of the *central cord circuit.* The *calling drop* is connected here in order to show the signaling of a subscriber to the

operator. The drop is a simple application of the electromagnet.

Figure 154 shows such a line jack, calling drop, and the plug of the cord circuit. The little armature that is released by the ringing of the subscriber's magneto exposes the number of the circuit and thereby calls the attention of the operator. The in-

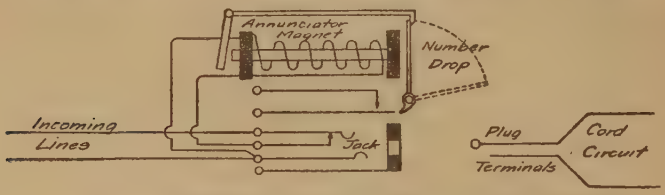


FIG. 154.—TERMINAL DROP, JACK AND CORD CIRCUIT AT TELEPHONE CENTRAL OFFICE

sertion of the cord plug into the jack connects the operator's listening and talking set to the subscriber upon depressing the listening key. This may be seen by referring to Figure 155. If the operator depresses the key in the reverse direction, the central ringing generator is connected to the plug of the calling cord and automatically disconnects the answering cord while the ringing is being accomplished. Therefore, to call any party, the operator has only to insert into that jack the calling plug and depress the ringing key. A *clearing out drop* responds to the ringing off signal from the subscribers and notifies the operator that conversation has finished. Such magneto type local battery systems are still employed in small country installations and give very good service; but, by far, the common battery systems are employed to the exclusion of all other types for use in the city, suburban, and long-distance service. In the common battery system the potential source is

maintained at the central office where it may receive better attention and care. Instead of the signals on the board for the operator's attention being of the drop type, they are now entirely of the visual light type. These are superior for many reasons, since they respond more readily; require far less space, a most important item; can be more easily seen; and act automatically in lighting and in extinguishing; whereas the drops must be reset by hand.

Figure 156 shows completely the circuit of a typical Western Electric common battery telephone wiring layout. The subscriber's apparatus is practically identical with that described above for the

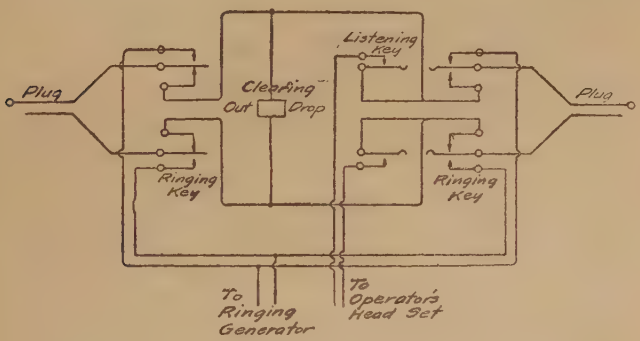


FIG. 155.—MAGNETO TYPE CENTRAL OFFICE CORD CIRCUIT

local battery system and differs for the main part only in its connections. Of course, there is no battery, since the potential source is located at the central office and is common to all subscribers; and there is no magneto ringer since the signaling is accomplished in a more convenient way. To signal the operator in this system, you have only to remove

from the hook the receiver and immediately a circuit is established from the common battery through the line relay at the central office, the lines, the primary of the induction coil and the transmitter.

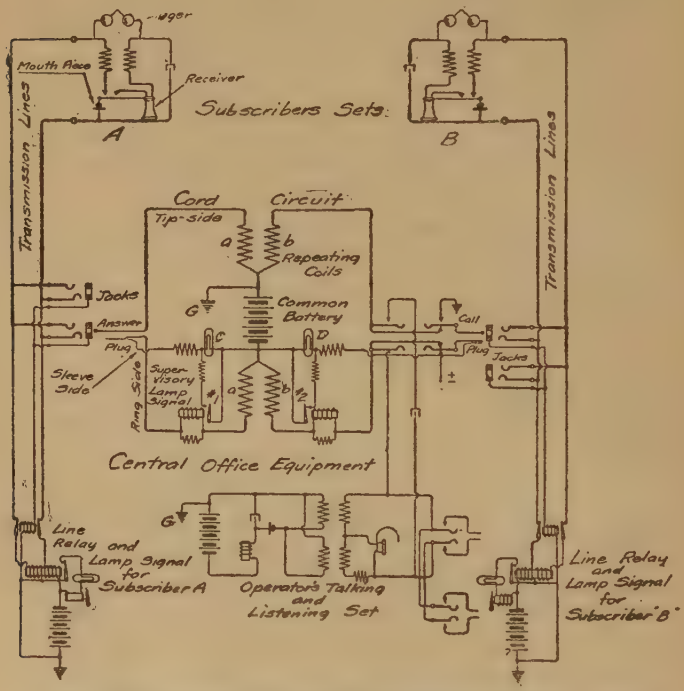


FIG. 156.—COMMON BATTERY TELEPHONE SYSTEM. SUBSCRIBERS' SETS AND CENTRAL OFFICE EQUIPMENT

This line relay, therefore, closes and lights the line lamp. Sometimes when the subscriber does not get immediate response, he moves the hook up and down very rapidly in his impatience. Since the relay cannot respond instantaneously, due to its weight and inertia, such signaling does not even cause the light to operate. The correct procedure is to move the

hook slowly up and down which would blink the light and more quickly attract the operator. The operator plugs the answer cord plug into the jack of the signaling subscriber, which procedure, as you can see, disconnects the line relay from the line terminals and automatically extinguishes the signal light and at the same instant connects the common battery to the line through the jack, thereby maintaining a continuous current through the line. This is all accomplished by the so-called *tip* and *ring side* of the cord circuit. There is, however, a third part of the plug called the *sleeve side* which is seen in the light lines of the plug. As the plug is inserted into the jack, a circuit is established from the ground side of the jack through the sleeve of the plug, the lamp, to the negative side of the battery and through it to the ground. This circuit lights the *supervisory* lamp "C" for just an instant as the plug is pushed in but goes out again as soon as the live current flows and causes the relay No. 1 to open the *supervisory* lamp circuit. The operator depresses the listening key and receives the number required. The *calling cord plug* is inserted into the *jack* bearing that number. This circuit is open circuited to the flow of a battery current. As the ringing key is depressed, however, the alternating current passes directly through the condenser and rings the bell. As soon as the plug is inserted in the calling side, a circuit through the supervisory lamp "D" is established and stays lighted until the subscriber "B" removes the hook. The operator knows that conversation is in progress by the fact that both supervisory lamps are out. As soon as the "B" subscriber removes the receiver, the hook closes the line circuit through the transmitter and a current from the

battery immediately flows, a condition which causes relay No. 2 to open the supervisory lamp circuit.

Obviously the battery current flows to each subscriber from the common battery. In fact, many hundreds of other circuits may be similarly energized from this common source. The two circuits, however, are separate in all respects so far as the electrical relations are concerned. Now, as the subscriber at "A" talks, the current flowing in the circuit varies in accordance with the variations in the quality and intensity of the speech waves. These variations in the two coils of the repeating coil "a-a" induce similar variations in the corresponding pair in the other circuit "b-b," which are converted into intelligible sounds by the receiver at the other end. The repeating coil is most commonly made of a toroidal ring upon which four equal windings are properly placed. It is equivalent to a one-to-one ratio transformer.

In the event that either subscriber hangs up the receiver, the circuit is opened from the common battery and the corresponding supervisory relay operates to light the supervisory lamp, thus notifying the operator that she may disconnect. If both subscribers hang up, of course, both lamps would light up. The common battery is composed of a battery of eleven storage cells to give twenty-two volts. The ringing system is an alternating-current generator, which gives about eighty to one hundred volts.

The systems as above described hold for an exchange where the lines of not over 500 subscribers terminate; but for more lines than that the operators could not reach from one position of the terminal boards to another to make the necessary connections. When the space from one position to the

farthest required becomes greater than can be accomplished conveniently, a multiple jack system must be employed, where each line terminates into two or more jacks, so that each line may be reached by every operator at the board. Such is the system employed in every large exchange. In order that an operator does not plug into a line that is already connected at some other board, a *busy test* is necessary. In this test the operator touches the plug to the jack and if the line is busy, the peculiar *busy test noise* is emitted and the operator calls back that "line is busy."

Not quite so simple are the connections in a city system, where more than one exchange is in operation. In general, it becomes tremendously expensive to install more than 10,000 lines on each board since the multiplication of multiple jacks complicates the system and rapidly multiplies the cost of installation. Consequently, when many thousands of lines are required, they may be divided into several local exchanges. In Greater New York there are about 125 exchanges in operation. Between each exchange there are many so-called trunk lines for the interconnection of lines terminating in the respective exchanges. For example, a subscriber removes the receiver and flashes a line signal at his exchange—say Hamilton. The operator plugs in and calls for the number he desires—say Columbus 1492. The operator then presses a call button for the Columbus exchange and over the *operator call wire* says to the Columbus operator—"Hamilton 1492." This tells the Columbus exchange operator that the Hamilton operator wants 1492 on her exchange, which she plugs in. The system of supervisory lights is somewhat more complicated in this case, but the same

general principles hold as explained in the above system. For long-distance circuits, trunk lines extend from city to city for use in connecting a subscriber of one city with one of a distant city. Sometimes many intermediate cities have to be plugged through in order to connect up the parties.

The circuits in the country and in suburban districts are usually carried overhead on poles. Better results are obtained through aerial transmission than with the underground system. The difficulties that were originally encountered in the overhead transmission of speech were almost insurmountable, and vast sums of money had to be expended to improve and extend the lines. A long pair of lines further had considerable inductance one with the other and with the earth, and also high electrostatic *capacity* between lines and also with the earth. These effects caused a rapid diminution in the intensity of the signals, as well as a distortion which rendered words spoken at one end unintelligible at the other. Copper wires have less resistance and are used for long-distance circuits more than iron wire, although the latter is stronger and may stand the mechanical stresses better than copper.

With underground cable, the electrostatic capacity is much greater than with overhead construction and, therefore, the engineering difficulty was here a greater problem. By transposing, however, the two wires of a circuit at certain intervals, the deleterious effects of the inductance may be alleviated. This was accomplished by using a pair of twisted telephone wires in which a complete twist was given every five or six inches. This constant transposition practically eliminates the inductance effect. In the very long lines, the mutual inductance

is reduced by frequent transposition and at certain long intervals inductance coils called *loading coils* are inserted into the lines to neutralize the effects of capacity. By a very careful balance of these line characteristics in the way just described relatively clear speech may be procured. Constant investigation is still in progress directed toward improving the transmission characteristics. Many of the power lines and other circuits that sometimes parallel a telephone circuit create continual disturbances on the lines by causing a humming or buzzing sound. The power lines must, in such cases, also be transposed in order to break up and minimize the disturbance. Where several telephone lines are running side by side on poles or in conduits, the noise of cross-talk becomes very annoying. The conversation on one circuit can be heard more or less faintly upon the adjacent lines. This is effectively stopped by well-designed transposition of the wires of each circuit and by the various circuits themselves.

The use of one metallic wire with a ground return was employed extensively in country and isolated systems; but such systems were abandoned in important installations, since the difficulties of cross-talk seemed to be insuperable. Even the *earth currents* of traction lines, where the current flows back to the power house through the ground, cause *telephone interference* that can scarcely be eliminated. So pronounced is this that one can clearly hear the starting and stopping and the speed variations of the car motor.

For efficient utilization of the capital outlay in the wire for long-distance trunk lines, a most unique device was invented called a *phantom circuit.* If

two complete circuits were running between two cities, each circuit or pair of wires can be used as one line of a *phantom circuit.* This is shown in Figure 157. Therefore a two-circuit system can hold three simultaneous conversations. As the number of metallic circuits increases, the number of

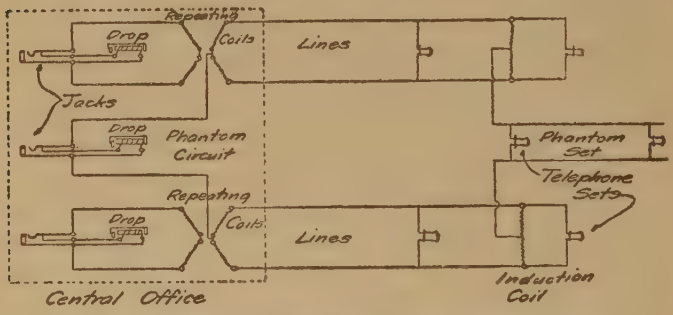


FIG. 157.—METALLIC CIRCUIT TRANSMISSION LINES SHOWING PHANTOM CIRCUIT

phantom circuits may also increase. Where several phantoms are employed, the transmission or trunk lines must not only be transposed to eliminate cross-talk between pairs of lines, but in such a way that cross-talk is minimized between phantom circuits as well. In the case of cables, a quadded type cable is constructed for this purpose.

The automatic telephone system made by the Automatic Electric Company of Chicago has been in use in the Middle West for about ten years, and has gained such popularity that the Bell Corporation has devised a system of its own which it is now installing in New York City. Already several exchanges are operating semiautomatically. In the automatic system, the phones have a dial with the ten fundamental digits from 0 to 9. This dial may

be turned from any one of these digit positions to a thumb stop by inserting the finger into the finger hole corresponding to the desired number. As soon as the dial is released, it springs back into its original position. For example, if the number 37 were wanted, you would place your fingers in the 3 hole and bring it around to the stop and let go, then you would do the same for the 7 hole. This procedure would immediately put you in connection with your party, whose bell would ring and continue to ring until answered, unless you restored the normal condition by replacing your receiver on the hook. The automatic connection at the central plant takes place more quickly than the eye can follow. Instead of the dozens of girl operators, supervisors, etc., two or three troublemen are all that are needed in order to keep a large station operating smoothly. The calls are made as rapidly as you can run the numbers on the dial. The exasperation caused by wrong numbers, undue delays, and frivolous replies are entirely eliminated by the automatic system.

The intercommunicating sets have supplied and still continue to supply a great service, where the many desks and offices of a factory or other organization are connected by means of such a telephone system. There are in a switch box as many push buttons as there are phones on the system. Each office has a certain number and button. To call any office it is simply necessary to press the button and the other bell rings for attention. Such systems are almost indispensable in certain lines of activity where constant information between department heads and various officials is desired.

The telegraph system has spread its lines to nearly every point in the United States. The West-

ern Union Telegraph Company and the Postal Telegraph Company, have practically full monopoly of the system in this country. The first electric telegraph method of transmitting communications over a distance was conceived and put into practical application by our famous and revered citizen, Morse, in 1837. He conceived the scheme as early as 1832 and for years worked thereon, devoting himself ceaselessly to the task of perfecting this monumental invention. For years, he stinted and starved, living most humbly in a small laboratory, buying his meals from the little grocery store, so that he could devote his entire time and income, of the most meager amount, to the satisfactory completion of his system. As Morse finally submitted his devices and system, they stand to-day without material improvement, and in this form bear evidences of his far-seeing genius.

There are in use two systems of simple manual telegraphy. The one, called the *closed-circuit Morse system,* is most widely employed in this country and that known as the *open-circuit Morse system* is used most extensively in European countries. There are advantages and disadvantages in the case of each type. In general, however, it seems to be acceded that the closed-circuit system is the more satisfactory. The apparatus is more simple, it is more convenient to install new stations and less difficulty and expense is attached to the maintenance of the battery system. Also, there are two systems of character alphabets by which messages may be transmitted. The one used universally in American practice is called *the Morse alphabet;* whereas the *continental code* is used almost exclusively in Europe. The basic principle of codes are the *dot* and

dash. The dash is a time duration equal to three dots. The entire system is deciphered on a principle of time duration between impulses of response to the taps of a key, thereby opening or discontinuing the flow of the current. The Morse code permits of more rapid transmission than any other system. A good operator can send about forty average five-letter

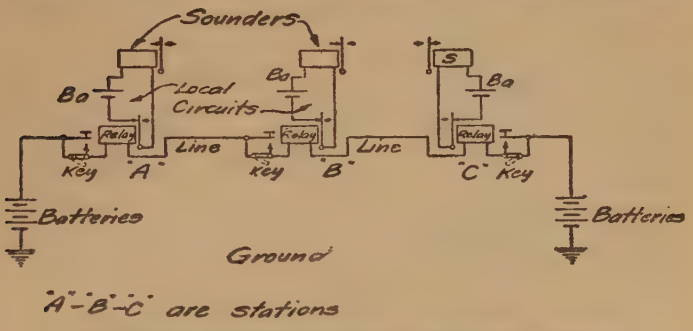


FIG. 158.—A MORSE SIMPLEX TELEGRAPH CIRCUIT

words per minute; whereas an expert, however for a short period only, may send as high as fifty-five words.

The Morse closed-circuit system requires the following apparatus for each station: a key, a main line relay, a local sounder, and a local battery. In addition, there is required on the system a main line battery preferably at each end of the line and a main line of single wire with a ground return. The wire is usually iron wire, but sometimes copper-clad to increase its conductivity. The long-distance lines called *trunk lines* are made of hard drawn copper.

Figure 158 shows the conventional diagram presenting the relations of the parts of the equipment at each station. The line is normally kept closed by the key switch of the keys at each local station.

There are in general two divisions of main-line batteries, one set at either end of the line. Or generators may replace these individual battery sets. At each station there is a relay in the main line which responds to a very minute current. The relay is a simple electromagnet with light-weight armature tongue which may be drawn against the action of a spring toward the poles and made to touch a contact point. When the circuit is opened by opening a key switch, the armature of the relay, no longer being energized by the line current, is drawn back by a retractile spring and ceases to make contact with a local sounder circuit. The sounder is a device quite similar in general principle to a relay except that the coil is heavier and has a much heavier armature and contacts, so that the sound may be distinctly heard over a large room. The relation of the relay and sounder in the local circuit is shown in Figure 159. The relay is a delicate device which actuates upon a very small current and operates the local sounder which gives loud signals of precisely the same nature as those of the relay. The armature of the relay is simply a switch for opening and closing the sounder circuit through the local battery. If station "A" wishes to send a message to station "B," the "A" operator opens the key switch several times to attract all the operators on the line, then he follows with the call of the particular station desired. Of course, all the operators are free to listen in.

The line current usually employed on a Morse closed-circuit system ranges from 0.040 to 0.050 ampere for 150-ohm relays; with 35-ohm relays, which are less sensitive, a line current of 0.060 to 0.075 ampere is usually employed. The local sounder circuit should use from 0.100 to 0.250 of an ampere,

depending upon the type and resistance of the sounder. The simple telegraph system is used particularly for short-distance transmission along railway lines, for train dispatching, fire-alarm signaling, police signaling, and private work. The relays and sounders have adjusting screws for varying the

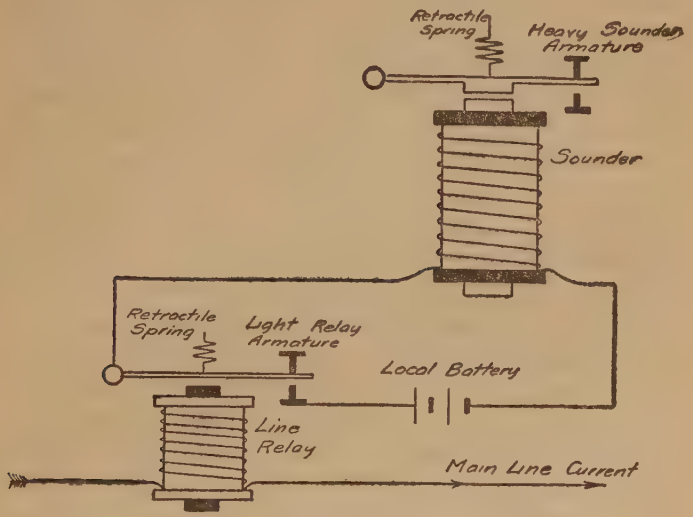


FIG. 159.—LOCAL STATION EQUIPMENT FOR A SIMPLE TELEGRAPH CIRCUIT

air gap, which affects the sensitivity of the instruments. On the long lines these adjustments are subject to frequent regulation due to the effects of the atmospheric conditions. During the wet spells there is considerable leakage of the electricity from the line to the ground. This means that the system must be adjusted for this condition.

For the important trunk lines employed for transmitting messages from one large city to another large city, the use of the simple telegraph system

would be very expensive and also very slow. In order to make greater use of the capital invested in the long lines by increasing the number of messages transferred over them, the quadruplex and multiplex systems are therefore used. An element of the quadruplex and multiplex systems as now operated by the Western Union and Postal Telegraph Companies is called the *duplex system.* This permits one message to be sent from each end of the line simultaneously without interference. There must, of course, be a sender and a receiver at each end, making a total of four operators required to a duplex system. In a quadruplex, four simultaneous messages may be sent over the one wire, two from each end, without interference. This would require two sending and two receiving operators at each end of the line or a total of eight operators for the operation of the one line.

The quadruplex system was first invented by Thomas A. Edison. At the time it was heralded as a system possessing wonderful possibilities. It has led to the ultimate invention of the multiplex system, of which the DeLong type has given most remarkable results. So ingenious was this apparatus that thirty-six messages could be transmitted in one direction and thirty-six in the other over one wire and without interference. Then, too, the speed of the expert operators soon imposed the limitations to the system and the high-speed telegraphy came into use. This method employed automatic operation of the sending and receiving. The sending end used perforated paper tape, somewhat similar to that used by the automatic piano-players. This tape was previously perforated on machines controlled from a typewriter. The messages were

written by typists at high speed on the typewriters. But instead of being reproduced in letters they appeared on the paper tape in a code of perforations. This tape was then run through the automatic sending machine, which forwarded the messages of the tape to the far distant city where they were received and transcribed on the standard forms by automatic typewriters. The only manual part of the entire operation was the perforation of the tape, placing it in the sending machines and taking away the separate sheets of messages ready for distribution by the messengers.

At present, composite systems are in vogue in which four simultaneous telegraph messages and five telephone conversations may be carried on without interference over one pair of lines. The object of all such systems is to employ to the limit the use of the wires already existing between stations. The cost of wire is high and the labor involved in stringing it is an uncertain element. Then, too, the more wires employed on a system the greater will be the expense resulting from additional insulators, safety devices, heavier poles and more inspection service. Rather than install more wires as the business expands, and it has expanded by leaps and bounds, the slogan has been to utilize more efficiently the lines that now exist by speeding up the words per minute and the messages per day by automatic machinery, and also by keeping the lines in constant operation. Therefore, the result has been that thousands of typists have been kept busy making perforated tape that the automatic sending equipment may never run out of feed. It is an inspiring sight to visit one of these great offices in New York, Boston, or Chicago and see these machines operating between every

large city in the country through the medium of the trunk lines. Repeating stations become a necessary adjunct to a very long line. Lines over 500 or 600 miles introduce so much distortion and diminution of intensity that at distances of about the above, a repeating station is installed. Here corrections for these distortion characteristics are made, so that the messages continue as at first impressed upon the line. Such operation is most essential to the long lines. This is necessary also on telephone lines. Between New York and San Francisco on the ocean to ocean route, there are repeater stations en route at Pittsburgh, Chicago, Omaha, Denver and Salt Lake City. These correct the distortions that would otherwise render the speech unintelligible.

The element of all these devices employed in multiplex systems is the so-called *polar relay,* which is the device used in the *polar duplex system.* There is another type of duplex system in which the principle of the Wheatstone Bridge is used. We shall confine our attention to the former. In Figure 160 there is a simple diagram which shows the working parts and principle stripped of the refinements in actual use on the system. The polarized relay, as the name indicates, operates for currents in one direction only. It consists of a double core electromagnet as shown in the figure with a permanent magnet N-S attached to the middle of the electromagnet as shown. To the free end of this permanent magnet is a soft iron armature pivoted free to oscillate from one side to the other. Normally, both tips "a-a" are of the same polarity and the armature tongue stays in the middle. Suppose equal currents flow through either core, then the legs are equally magnetized and still the tongue is not attracted. If, however, one

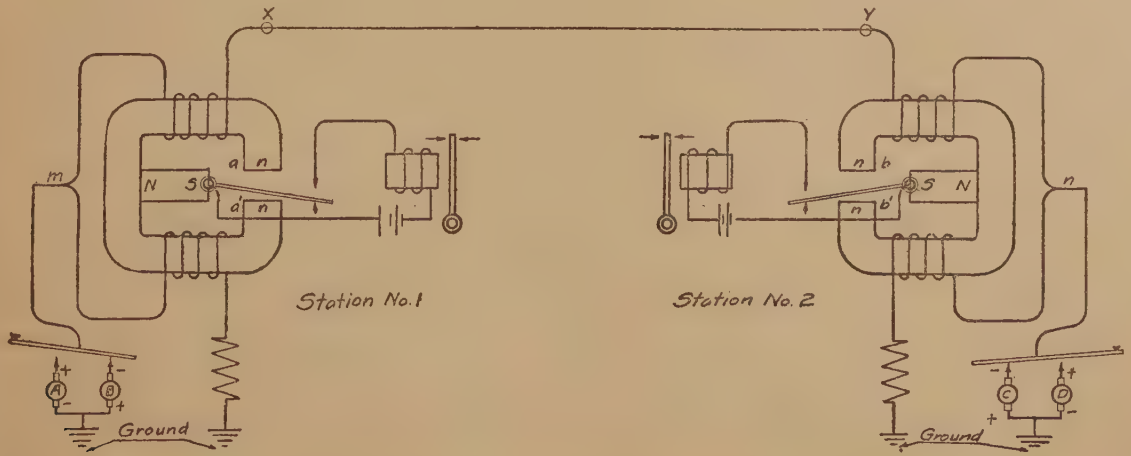


FIG. 160.—DUPLEX TELEGRAPH EQUIPMENT SHOWING THE PROPER WIRING CONNECTIONS

coil has double the current that the other has, then the tongue will be drawn to one side or the other. Like the tongue of the line relay in the simple system, it serves to energize the sounder circuit one way and to open that circuit in the reverse way.

The operation of the circuit is as follows. The permanent magnet "N-S" makes a-a^1 and b-b^1 a weak N-pole. When both keys are in their normal positions, as shown, current flows from generator "B" to ground through the artificial line, which has a resistance equal to that of the main line from "x" to "y" plus the combined resistance of the apparatus at station number 2 to ground, thence through a coil and back to the generator through the key. This current forms at a^1 a strong N-pole and keeps the tongue drawn. A similar result occurs at station number 2 from generator "C." Since equal negative polarities are presented to the line from "B" and "C" no current flows in the main line of coils of "a" and of "b." Now let the operator at station number 1 begin to operate the key by depressing it. The following action takes place: The positive polarity of "A" is presented to the line which sends equal currents through the two circuits which divide at "m," since these have equal resistances. Therefore, the tongue of station number 1 is not affected by the home key; and it should not be. Since generators "A" and "C", however, now operate in series, twice the current should flow through coil "b" as through coil "b'" and, therefore, since pole tip "b" becomes much stronger than at b^1, the tongue is drawn up and operates the sounder in response to the depression of the key. Or, if the operation is from station number 2 rather than from station number 1, the same operation will be true in the reverse sense, that

the polar relay of station number 2 should not respond to the home key while at the distant station number 1 the signals may be read. Therefore, one sees that each operator may actuate the system individually. Now let us consider the resulting action when the key of station number 1 is depressed while the operator of station number 2 operates his key. The tongue of station number 2 is up in response to key number 1 being depressed. As key number 2 is now depressed, the voltage of generator "D" being equal and opposite to that of "A", no current flows through the main line and the current through coil "b" flows in such a way as still to make the tongue remain up—that is, the home key does not affect the home relay, a condition which is correct, but the distance relay should respond. We find that it does since the coil of "a" make a^1 a south pole and repels the tongue. Therefore, it is clear that each key will affect the distant relay and not the home relay whether the two keys are operating simultaneously or not.

The quadruplex system operates with two keys at either end and employs the use of the polar relay and other apparatus to accomplish the operations. One set of relays and keys actuate exactly as above, whereas a second system actuates by virtue of two values of current having different strengths.

No difficulty is encountered through the ground return system by the cross-talk that will result from such systems in telephony. The reason for this is that the telegraph apparatus is far less sensitive to the response of signals than is the telephone. On long-distance lines, however, it is necessary to have some condensers to assist in balancing the artificial line of the multiplex system. If the current of the

signal impulses do not build up in the main line circuit and in the artificial line circuit at the same rate, the home relays may give responses and actuate through the operation of the home keys.

The balancing of the lines must be accomplished from time to time as the atmospheric conditions vary. As the lines become more or less leaky the artificial line resistance and capacity must be varied. This is readily and easily accomplished by the aid of certain meters that are available.

The problem of sending several telephone messages over one pair of lines seems equally amazing to that of the multiplex telegraphy. It is accomplished in a most ingenious manner. It is a well-known physical fact that if one tuning fork is set into vibration and maintained in this vibration by say an electromagnetic system, that any other near-by forks having the same natural period of vibration will begin to vibrate because of the impulses of the air waves in beating synchronously against them. The forks, however, that have a different vibration rate will not respond. Perhaps, five differently pitched tuning forks may be caused to vibrate. If five similar forks are present each will vibrate in its own frequency. Any other forks having different pitches from these five will not vibrate.

In the case of a pair of telephone lines let alternating frequencies of say 30,000, of 40,000, of 50,000, of 60,000 and of 70,000 cycles be impressed upon the system. Let the voice waves from one telephone be superimposed upon the 30,000 cycle alternating current waves; then let another telephone modulate similarly through suitable devices for the 40,000 cycle system and so on for the others. At the receiving end we must have a device that will respond

only to the 30,000 cycle wave, another that will respond only to the 40,000 cycle wave and so on. This receiving device must be capable of segregating the particular frequency to which it is attuned and of amplifying, to audibility, the speech waves. The simultaneous action of a multiplex telegraph system upon such a telephone system does not materially complicate the arrangement. With two such systems operating from and to the same stations, a phantom circuit may be employed to multiply the number of possible communications. These features are being improved upon and are receiving the attention of the experts of the world that the limiting conditions may be further removed and that the present wonders of the world may be even further increased.

CHAPTER VI

AUTOMOBILE ELECTRIC SYSTEMS

ONE of the most extensive everyday applications of electricity is in connection with the ignition, starting, and lighting of automobiles. Indeed, under the control of every driver or operator of an automobile is a system of electrical generation and operation fully as complicated as that which would be found in a small power plant. The operator puts his foot on a small pedal and immediately the engine is automatically cranked. Not more than five or six years ago such starting was accomplished by the brawn and muscle of the right arm. As a result many weak backs, fits of temper, and in some instances broken arms were recorded when the engine would either not start at all, despite considerable cranking, or would backfire violently.

When the engine has been started by the automatic starter system, its operation is continued through its own power and the automatic starting device may be released from action. The very operating of the engine, however, demands the actuation of certain electrical parts which constitute a more or less complicated system. As any automobile owner can testify, the ordinary garage man is at an absolute loss in tracing down difficulties of an electrical nature. He invariably blunders along trying one thing after another with the hope that if it is not

the one it will be the other. Consequently, much time is consumed and a shocking bill therefor causes the owner discomfort and an earnest desire to know more about electricity in its application to the automobile.

One of the first lessons that the operator should learn through such a costly experience is that the little ammeter in front of him must register a charging current during a considerable part of his car operation. If this is not true, he will find that the storage battery—"the black mystery box"—will go dead and probably be ruined and that a new battery must replace it. Many times the operator is warned that if he is doing city business driving where constant starting and stopping is necessary, the battery must be charged at a higher current rate; whereas in long-distance running a lower current charge for the long period will give the best condition. Further, the driver is told to observe certain precautions in the care of the storage battery. These certainly do constitute a nuisance and are thus disregarded by many with the unfortunate result, possibly, that far out in the country highway his car stalls, fails to start and the series of unpleasant experiences and the condemnation of a perfectly good car and electrical system begins. The operator thus proves that he is not sufficiently honest to admit the failure of his part in the contract. In reality, between any machine or mechanical or electrical mechanism and its operator, there is a rigidly drawn contract more unviolable than that between man and man. This contract demands certain points of attention on the part of the operator to the machine. If these are carefully observed, the engine or machinery will be kept in smooth running and

will cause no trouble but give absolute satisfaction. The break in the contract, however, will almost invariably occur on the part of the operator who, being human, will fail to keep up the end of the bargain under his control.

Then, too, as darkness steals upon the highways and byways, certain laws for safety demand that headlights and a rear red light be shown. The headlights, of course, are also intended to make the road conditions plainly visible. These lights as well as many more which are located for the convenience of the passengers, are electrically operated. Yet only in case of failure in their performance is any special care directed toward their condition and that of the lighting agent.

The many sources of annoyance that are possible on any automobile can be made negligible only by giving the automobile ignition system the consideration that any complicated machinery must have. Of course, the designers of such layouts do give considerable attention to the simplification of the last detail and to making the equipment as rugged as possible to withstand the strains and undue wear occasioned by unskilled and careless manipulation. But in spite of the efforts of the designers, the systems of electrical construction still remain complicated to the uninstructed layman, and as a result his ignorance is repaid by excessive maintenance charges. Unquestionably no other power plant than that found in the automobile receives such unskilled and haphazard attention. Even a small 25 or 30 horsepower motor generator set for supplying possibly a small hotel receives the services of a careful, skilled, and experienced man in its operation and maintenance. Yet, the great power of the

Packard Twin Six or the Stutz will often be intrusted to the care of a man who could not tell you whether the engine used the pure liquid gasoline or whether it entered the cylinders in a jelly form. In fact, his only knowledge about the car is the operation of certain foot levers and control rods to accomplish the necessary maneuvering to pass the road test for an owner's license.

A brief outline of the cycle of operation of a gas engine as used in automobile propulsion will be considered together with the appurtenances necessary to give the complete action. The universal type of engine employed for automobile operation is that known as the *four-cycle engine.* An engine in operation goes through a certain cycle of events over and over again. These may be summarized as follows in the case of the gas engine: The first event is the *intake* or *suction stroke,* in which a charge of gasoline vapor mixed with air is drawn into the cylinder as the piston moves downward. The second event is the *compression stroke* during which the piston moves up the cylinder and compresses the charge of gas previously drawn into it. The third event in the cycle is the *expansion* or *explosion* stroke where the compressed gas, as the piston reaches the top point of its travel in the compression stroke, is ignited by an electric spark which causes the gas to explode with the exertion of great force in pushing down the piston. The fourth and last event in the cycle occurs as the piston again moves up the cylinder and *exhausts* or *dispels* the burnt gas or product of the combustion. This stroke is called the *exhaust stroke.* The four events in the cycle of the gas engine, therefore, are, briefly: intake, compression, combustion, and exhaust. Since

one stroke of the piston occurs for each event, it is called a *four-cycle engine.*

In the successful operation of this cycle of events, there are certain functions that must be executed by auxiliary apparatus. The gasoline must be properly mixed with air in order to produce the highly explosive gas, a process called *carburetion.* Also essential is the equipment necessary to explode this gas mixture at the exact moment when the compression is greatest and the piston is at the end of its travel. There must be a passage of an electric spark at the proper instant through the gas in order to ignite it. This spark must be a fat, hot spark, rather than a lean, blue discharge which does not carry much heat with it.

The process of mixing the gasoline with the air is accomplished in a very important little device sometimes called the *heart of the gasoline engine,* but known technically by the name *carburetor.* As you probably know, gasoline in its liquid form is not explosive and will in fact put out a fire if poured directly upon it. When the gasoline, however, is sprayed into a very fine mist and then mixed thoroughly with air, a gas is formed that is not only inflammable but even highly explosive. In order to obtain the proper results, it is essential that the air and gas be mixed in proper proportions. It is the function of the carburetor to perform mechanically the proper mixture. If too much gasoline is present, a condition called a *rich mixture,* which produces slow and incomplete ignition, occurs and a black smoke is given out in the exhaust.

The parts of a carburetor may be seen in Figure 161. Besides providing a mixing chamber for the air and gas, it should also function to control the

proportions of each. These proportions vary with speed and with load, a set of conditions which complicate the design and the operation of the carburetor.

The intake manifold or pipe system for the engine is attached to the carburetor so that the intake or suction stroke draws in the gas mixture from the

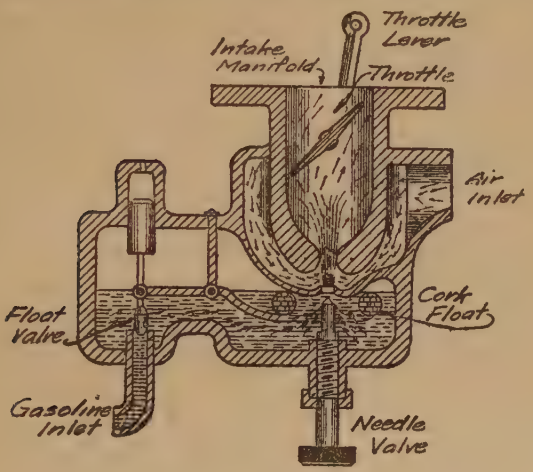


FIG. 161.—SECTIONAL VIEW OF A CARBURETOR

carburetor. The gasoline supply to the carburetor feeds either by gravity or a forced system from the supply tank and enters through a float valve into a reservoir as seen in the figure. When the cork float rises to the proper maximum level for the gasoline, it closes the float valve through the mechanism of levers and thereby closes off the supply of gasoline. A needle valve is so located under a mixing chamber, that as air is drawn into this chamber by the intake stroke of the engine, the gasoline is caused to spray in a very fine mist up into the mixing

chamber and thence to the engine cylinder. The air enters through an air inlet valve and is screened by a fine meshed sieve. The supply of gasoline, in order to get the proper mixture, may be regulated by the needle valve. As the spray of gasoline acts, the level of the supply in the reservoir drops, lowering the cork float, which in turn slightly opens the float valve and permits more gasoline to feed from the supply tank. The throttle valve, actuated by the hand or foot control by the operator, adjusts the amount of the mixture entering the manifold from the carburetor. It does not affect the proportions of the mixture, but only the quantity of the gas in its finished, mixed form.

The diagram of the carburetor shown above will be found helpful in an understanding of the principle. In actual operation, such a simple device would give very unsatisfactory service at varying speeds and loads. The greater the rate of flow of the air, the more gasoline would be drawn through the needle spray valve. This means that the proper adjustment at slow speed would give too much gasoline at high speed. The mixture being too rich would result in unsatisfactory operation. If at the high speeds an additional supply of air would be added, the mixture would be kept practically uniform at nearly all speeds. Such speed compensation is accomplished by an auxiliary air intake valve which comes into operation only at the higher speeds. This valve is held closed by a spring tension and only the increased suction of the higher speeds are effective in opening it. Such a carburetor is called the *compensated type* and is used almost exclusively on automobiles at the present time. Not the same degree of mixture is advan-

tageous for all conditions of car operation. For quick getaway richer mixture is found to be best having a ratio of air to gasoline approximately 12 to 1. For high speed operation a *lean mixture* of about 17 to 1 has been found best. Such changes are in certain makes of cars under the control of the operator.

Perhaps on the cold winter mornings you have seen your neighbor exerting great effort in trying to start his engine; or perhaps you even have ruined a storage battery by trying to start the cold engine from the self-starter. Such cases are most frequently observed. A scientific principle lies behind and explains the cause. The fact was early discovered that cold gasoline and air do not mix readily or thoroughly. In order to have a uniformly mixed gas it was found necessary to have the air and the gasoline warmed. Tests proved that 170 degrees Fahrenheit was the most effective temperature.

This heating which adds greatly to the fuel economy may be accomplished in several ways. First, by having an electric heating coil wound about the carburetor; second, by passing the heated water of the water circulation system through the water jacket about the carburetor, third, by passing the exhaust gases through such a jacket instead of the water; fourth, by passing the air supply to the air intake through a jacket over the exhaust pipe; fifth, by properly locating the carburetor between the cylinders of the engine as well as warming both the air and gasoline supplied to it.

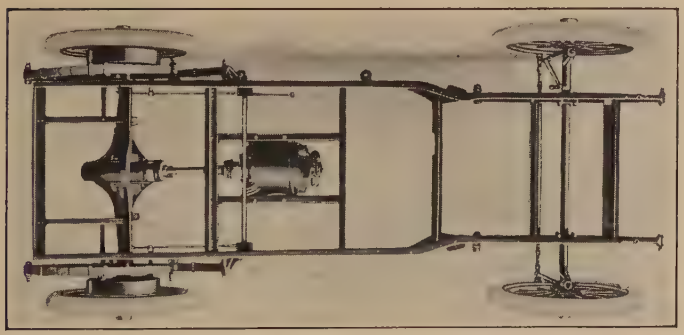
A carburetor has very sensitive adjustments and should not be tampered with as long as it is working satisfactorily. Look for trouble elsewhere first. There are several tests that can be given to ascertain

the conditions of the cylinders and spark. If the trouble is not in these places, then the condition of the carburetion should be noted. Test for the compression in each cylinder and try out the ignition to see that a bright spark occurs for each cylinder in the proper firing order and at the proper instant. When the flooding pin which holds down the cork float is depressed, the carburetor should flood and leak gasoline. If it does not, then there is stoppage in the supply pipe and in the needle valve, caused by either a closed shut-off valve or a clogged dirty strainer. If the gasoline floods the carburetor when the car is standing, there may be an obstruction under the float valve, a leaking float or a leak at some connection.

If the motor runs but has a succession of popping noises in the exhaust as the throttle is suddenly opened, it indicates that there is too lean a mixture —the gasoline needle valve should then be slightly opened. A sluggish response to the throttle valve with a black exhaust smoke indicates too rich a gas, in which case the proper regulation may be obtained by closing slightly the needle valve. The adjustments should be made on the carburetor when the motor has been run until all parts are heated to the average running temperature.

A very important part of any gasoline engine is the valve system. There are always two valves, one the *inlet* and the other the *exhaust valve*. These must be opened and closed at certain intervals and the exact action of their time element of opening and closing is of the utmost importance to the proper running of the engine. These valves are actuated mechanically from a cam rod. The inlet valve is opened just as the piston starts downward

INSIDE AN ELECTRIC AUTOMOBILE



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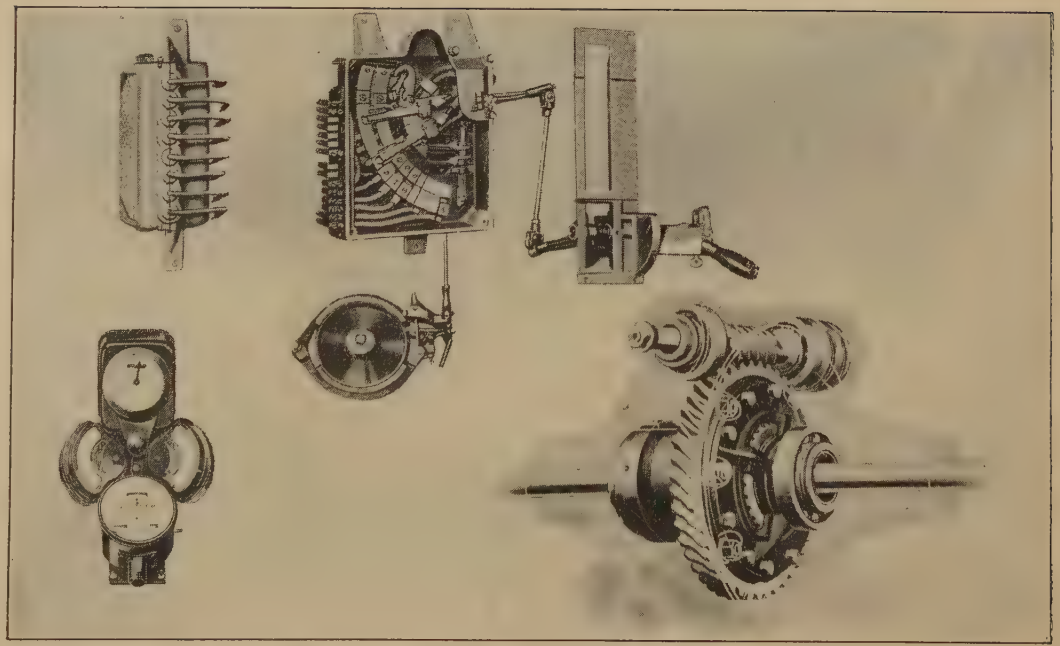


MECHANISM OF AN ELECTRIC AUTOMOBILE—SPEEDOMETER, CONTROLLER, WORM AND WORM WHEEL, ETC.

and should remain open until it has reached its lowest travel. As compression begins, this valve must be perfectly seated in order to prevent any leakage of the gas pressure. After the expansion stroke, just as the piston starts up, the exhaust valve should open, so that the rising piston will force out

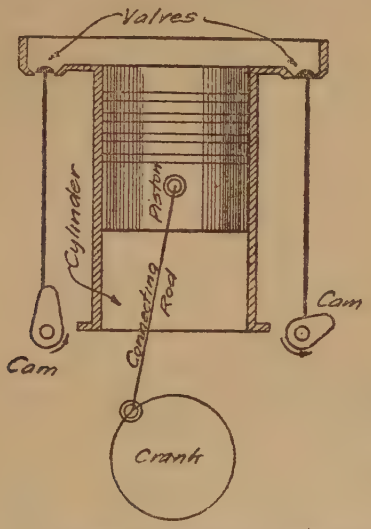


FIG. 162.—CYLINDER, PISTON, AND CAM MECHANISM ON A GASOLINE ENGINE

the burnt product of the combustion, which valve should promptly close as soon as the piston reaches the top of its travel. Both valves open inward, so that the pressure of the power and compression strokes effect the best seating. Of course, the engines have widely different-shaped cylinders, all of which are designed for varying means and purposes. Figure 162 shows a cylinder with its piston and the inlet and exhaust valve actuated by a cam device. The cam shaft must revolve at just one half

the speed of the engine shaft, since the engine makes two revolutions per cycle of events, and yet the valves must actuate only once for each cycle or, therefore, once for each two revolutions of the engine.

IGNITION

Every automobile at the present time has at least four cylinders, while many different makes use six, eight, and twelve cylinders. It would be highly impractical to fire these cylinders in consecutive order since there would be a swaying of the engine which would set up a system of strains in the mechanism that would soon ruin the engine. The cylinders are universally numbered consecutively 1, 2, 3, etc., starting from the radiator end. In order to equalize the tendency to set strains in the motor parts, a definite order of firing of the cylinders depending upon the type of engine must be employed.

The crank shaft of a four-cylinder engine is made so that cylinders one and four are displaced 180 degrees from two and three. In other words, when pistons one and four are on dead center up, pistons three and two are on dead center bottom.

The firing order for the four-cylinder machine may, therefore, be either 1-2-4-3 or 1-3-4-2.

In the case of a six-cylinder engine the individual cranks are located 120 degrees from each other rather than 180 degrees, as in the four-cylinder. Here again a certain definite order of firing is essential. The order may be quickly determined at any time from the following diagram. Figure 163 shows each cylinder located 120 degrees from the other.

There are two kinds of six-cylinder crank shafts called respectively *left-hand* and *right-hand shafts.*

It is a right-hand crank shaft if, when looking from the radiator end, pistons one and six being up, pistons three and four are on the right of the one and six pistons. If pistons three and four are to the left of one and six, when the latter are up, it is a left-hand crank shaft. Going around to the right, that is in a clockwise direction, the firing order is 1-5-3-6-2-4 for a right-hand crank shaft. In the left-hand rotation the firing order is 1-4-2-6-3-5 for a

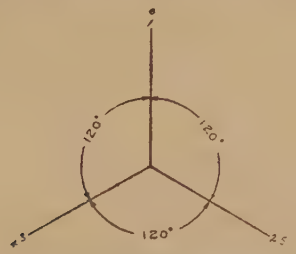


FIG. 163.—ANGULAR DISPLACEMENT OF CRANKS ON A SIX-CYLINDER GASOLINE ENGINE

left-hand crank shaft. For eight and twelve cylinder firing, the orders of fire are respectively the same as four and six-cylinder engines, where the cylinders are placed four or six in a set on one side, the other set being at an angle or "V" with the first.

The universal arrangement of the ignition system in the cylinder of a gas engine is to have the spark applied to the compressed gas just at the end of the compression stroke as the piston is at the top of the stroke. The spark occurs between the points of a spark plug. The electric current is caused to jump across the intervening space from one point to the other, which distance should not be more than 1/16 of an inch. There are many different ways of causing such a current to flow. These will be dis-

cussed in the following pages. The instant at which the spark occurs in the cycle should be capable of being shifted, depending upon the conditions of speed, etc. If hand cranking is being employed, however, the spark must be retarded so that the ignition does not occur until after the piston has advanced beyond its uppermost point and is on its descent, otherwise the piston might "kick back" and break an arm, as sometimes does happen. In the case of high speed, however, the ignition should occur before the piston actually reaches the top of its upward journey. The reasons for such shifting of the sparking period will become clear if we consider the fact that the entire mass of confined gas is not all ignited instantaneously. The time of lag must, therefore, be considered more and more minutely as the speed of the cycle performance is increased. The advancing of the spark means the establishment of the spark earlier in the cycle, whereas the retardation of the spark means the reverse. The control of such ignition is accomplished by the operator by a lever which is available at the steering wheel. Sometimes, however, certain manufacturers make the control automatic by means of a governor device or otherwise. In general, though, it is true that in any mechanical device whatever the reliability and comfort of operation lies in the simplicity of the mechanism rather than in the complexity of the parts. A man who is to operate and care for his own car should select one in which the manufacturers have reduced to an absolute minimum the complications of parts that are certain to cause trouble by getting out of adjustment. A moving power plant that is constantly jounced over rough roads and is under constant vibration should

have a minimum of parts to become loose and cause trouble.

Fundamentally, all ignition systems are high tension, since the spark plug is caused to spark by the high voltage that is impressed across and thus causes the current to jump from one point of the plug to the other. The ignition system, however,

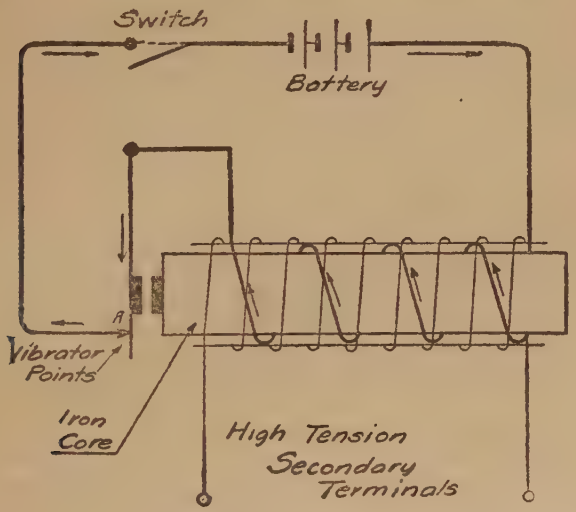


FIG. 164.—INDUCTION COIL

is classified principally through the type of generation of the electricity employed. It may be generated as a high-tension or as a low-tension system, thereby establishing the two general classifications. The magneto gives a high voltage which is distributed to the cylinders in the proper firing order. In the low tension generation, the low generator voltage is caused to become a high voltage by the use of induction coils. These coils are combined transformers and converters. They are excited in the

low tension side by a direct current and produce on the secondary side a very high voltage of several thousand volts. The coils are so extensively used in the ignition systems of automobiles that the principle of their operation will be considered at this time. The main parts are shown in Figure 164. The coil consists of a few turns of heavy wire, wound upon an iron core, producing the primary to which a generator or battery or other direct current source may be connected. Over the primary coil is wound the secondary coil of thousands of feet of fine wire, the terminals of which go to the spark plug.

A spring vibrator operates in conjunction with the iron core as shown in the above figure. Current from the battery flows through the contact screen "A" into the vibrating spring and thence into the primary coil and back to the batteries. As the current begins to flow in the primary circuit, the iron core becomes magnetized and draws in the spring which breaks the connection at "A" and thereby opens the circuit. The magnetism immediately dies from the iron core and permits the spring to fly back into contact at "A" and builds up the primary current again. This process then is one of continuous and rapid *make and break* of the primary circuit. As the magnetism in the iron core rises to a high value and then decreases to a minimum value, thereby cutting the turns of the secondary coil, the voltage induced in the secondary coil is very high. In order to absorb the spark of the make and break at the contact "A," as well as to increase the efficiency of the coil, a condenser is placed across the contact points. There may be a coil for each cylinder as in the Ford car, or there may

be one coil with a *distributor* in the high tension side in order to fire the various cylinders.

In general the complete electrical equipment of the modern automobile includes three functions. These are *starting, ignition,* and *lighting.* Sometimes each of these is entirely separate from the rest in which case it is called the *three-unit system.* In other cases, however, two of the functions may be performed from the same general equipment which is truly a *two-unit system.* If all three performances originate from one source of power, it is called the *single-unit system.*

For starting there must be a motor which is excited and operated from the storage battery. This motor must be mechanically connected to the engine shaft during the starting period. For the ignition, there must be some source of electrical energy as a storage battery, dry battery, magneto generator or common generator. There must be some means of transforming the low-tension current to high-tension current as well as distributing this to the proper spark plug at the proper time. For the lighting there must also be a source of electrical energy such as a storage battery, which may give excellent service for lighting and signaling equipment. In this case a generator is necessary as a means for charging the storage battery. The generator must be equipped with a device automatically to disconnect it from the storage battery at low speed, when its voltage is lower than that of the storage battery.

If the three-unit system is used, the apparatus for performing each of the three main functions is a separate unit from the others, the storage battery being the only common connection. With magneto ignition in such a system, however, there is no con-

nection at all between the parts of the electrical systems. In the two-unit system, two of the main functions are performed by one single machine, the third function being performed by a second unit. The generator may be fitted for ignition purposes with an induction coil contact breaker and distributor and may also be properly connected to the storage battery to supply energy to it for the lighting and signaling purposes. The cranking of the car in this case will be accomplished by a second unit—*a starting motor.* In some two-unit systems the generator and starting motor are combined into one single unit; the ignition in this case being accomplished by a second unit. The ignition may be performed by a magneto or by an induction coil and distributor, the current being received from a generator. Such a generator motor unit may be accomplished by building two distinct fields and armature windings for the motor and generator action. A commutator may be placed on either end of the armature with two separate windings as for a dynamotor.

In the case of the single-unit system, the above mentioned three functions required of any system, namely, the ignition, lighting and starting, will all be performed from the one unit. A device which may be either a motor or generator or both simultaneously, called a dynamotor, has two complete and electrically separate armature windings. One winding is associated with a commutator at one end of the armature, while the second winding is connected to a commutator at the other end of the armature. Such a machine for the purpose of automobile requirements may be built with a contact breaker, induction coil, and distributor in one unit.

The well-known "Delco" system employs, among other types, one of this nature for certain uses.

THE IGNITION SYSTEM

As previously explained, in considering the fundamental principles of gas-engine operation, the compressed gas in the cylinders must have an

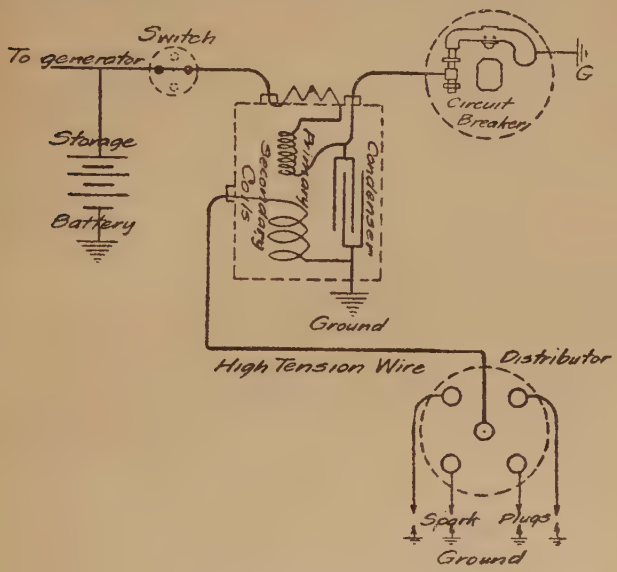


FIG. 165.—LOW-TENSION IGNITION SYSTEM ON AN AUTOMOBILE

electric spark applied to it at the proper instant in order to ignite the charge and, thereby, derive the power stored up in the charge. This spark may be produced, as considered earlier, by means of a generator, battery, or magneto. In Figure 165 is shown a cut where the ignition system is laid out in a clear, concise manner. A battery is shown which supplies

energy to the primary coil of an induction coil. As the engine speeds up to a certain point, however, it in turn supplies energy to the coil and to the battery as well, thereby applying the necessary charging process to it. As the engine speed decreases below this certain point, the generator is disconnected from the circuit by means of an automatic switch or relay so that the battery will not discharge through it, the generator voltage at low speeds being less than the battery voltage.

The current which flows through this primary circuit from either the battery or generator is periodically interrupted by the opening or closing of a circuit breaker, being operated from a cam associated with the shaft of the engine. The magnetic field of this primary coil current cuts across a secondary coil as it increases and decreases with the rapid interruptions of the circuit. In so doing a very high voltage is induced therein and by means of the device called the distributor, it may at the proper instant be applied to the cylinder which is ready to be fired. The function of the distributor as it is interposed between the high tension coil and spark plugs is to connect properly the cylinder which is ready for ignition in the order of firing as previously explained.

A condenser is always connected across the terminals of the *contact* or *circuit breaker* to perform the very necessary function of absorbing the energy of the spark and thereby save the contacts from excessive burning and rapid destruction. This condenser, however, does more than this one function in the system. It acts to increase the efficiency of the spark coil and has a most effective action in the operation of the induction coil. As the circuit

breaker opens, the current flow is interrupted. The spark which would normally occur at these opening breaker points is absorbed by the condensers, and the magnetism in the primary coil begins to collapse to a zero value. The energy absorbed by the condenser, however, now immediately discharges back through the primary circuit, causing a current to flow in the reverse direction. This current with its associated magnetism opposes that which is dying away and acts to hasten its decay to zero. In so causing this action to take place, the induced voltage in the secondary circuit is made very much higher. One will recognize the truth of this statement if he remembers that the magnitude of any voltage depends upon the amount of magnetism cut in one second. If a certain strength of magnetism is cut in a second, a certain value of voltage is induced. If this magnetism is cut in one-half the former time, then the voltage induced will be twice as great. In other words, the more rapid the rise and collapse of a magnetic field, the higher will be the voltage induced.

For ignition purposes a magneto is often employed for the generating unit. As such it may be of three different types, namely, the *low tension, high tension,* and *induction magnetos.* These operate as follows: In the low-tension magneto, the armature is wound with one continuous coil of wire. One end of this armature coil is grounded whereas the other end is taken out through a contact breaker and thence to the primary of a coil as for the case of the battery system above and through the primary ground. The secondary of this coil connects with the spark plugs which it causes to operate. The current is taken from the magneto armature by means of a brush.

In the case of the high-tension magneto, we have such a different type of system from the former one that Figure 166 showing the relation of the parts will be introduced. Upon its armature core is wound a coil as in the low-tension type above discussed. In addition to this, however, there is also wound a high-tension coil or secondary as in an induction coil.

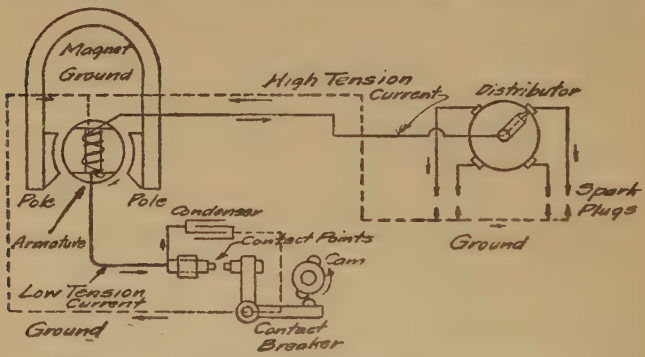


FIG. 166.—HIGH-TENSION MAGNETO SYSTEM ON AN AUTOMOBILE

One end of the low-tension coil winding is grounded to the armature iron, whereas the other end passes through the contact breaker before its circuit is made complete. One side of the secondary circuit is also grounded, the other being taken from the rotating armature by means of a carefully insulated ring and brush. This circuit is taken to a distributor and there connected at the proper instant and in the proper firing sequence with the cylinders undergoing the compression. In some types of high-tension magnetos, the condenser for the contact breaker which is made of mica and the contact breaker itself are in one complete unit, and are most compactly made.

In the inductor type magneto, a principle is used which is identical with that applied in the inductor type of alternating current generator manufactured by the Stanley Company. The armature coils and the field coils are held rigidly stationary. Between these coils revolves a mass of iron, which varies the intensity of the field magnetism about the armature coils and in this way generates therein a voltage. This type of unit obviates the necessity of any moving coils, sliding and wiping contacts, collector rings, etc. The insulation problem is in this case reduced to a simple one.

AUTOMOBILE LIGHTING

In no small measure does the safety of the operation of automobiles in the evening depend upon suitable and satisfactory lighting. There must be a reliable steady source of energy which will give out energy whether the car is moving or at rest. Such lighting may be given by a generator, when the car is running at such a speed that the generator voltage exceeds that of the storage battery, whereas in the reverse case, the storage battery will supply a constant voltage for this lighting purpose.

There are in general three systems of wiring for lights in use. The two common types are the single-wire and the two-wire systems. The third system, which is not used much, is the three-wire system. In the one-wire system, one wire leads the current to the lamps. The current passes through the lamp filaments and then returns to the generator or battery by means of the steel frame of the car rather than by a system of wires. This is sometimes called the *ground return system.* The advantage of this type lies principally in the fact that the wire is

conserved, thereby saving in expense and also simplifying the system. In Figure 167 is shown such a system for a six-volt generator, the most common system. In the case of the two-wire system the return instead of being through the frame is accomplished by a return wire. The advantage of the two-wire system is that if one wire becomes

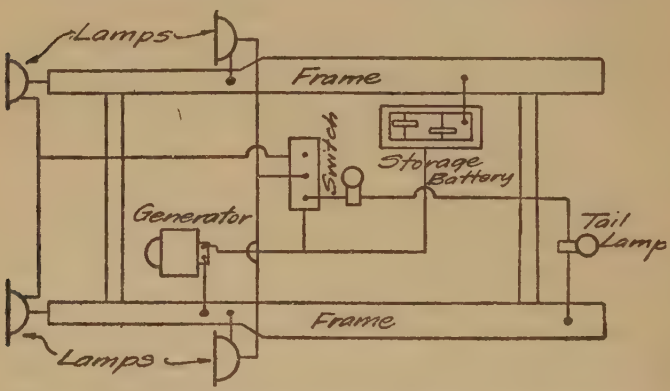


FIG. 167.—SINGLE-WIRE GROUND RETURN AUTOMOBILE LIGHTING SYSTEM

grounded by wearing or dampness, the system is not incapacitated as would be true of the one-wire system.

MOTOR STARTER

No convenience in automobile operation stands out more prominently at the present period than does that of *self-starting devices*. The heavy cranking often required more physical effort than some men cared to exert and therefore prohibited the free use of the car by women. These facts have made the installation of the electric starter almost a common practice with all makes of cars. The simple pressure of the foot on a pedal, is now the almost uni-

versal method of starting a car on its way of pleasure or business.

The motor takes its starting energy, a current of eighty to one hundred and fifty amperes, from the storage battery. This large current, however, flows only for a few seconds. The usual speed of the engine during the starting period is about 100 to 200 revolutions per minute. With the proper adjustments of the spark intensity and fuel mixture, the engine should readily start at such a speed.

The motor is so geared in respect to the engine shaft that it revolves ten times faster in order to derive the benefit of a starting torque for the engine at a less expenditure of energy. This means that if the gas engine is running at 200 revolutions per minute the motor is revolving at 2,000 revolutions per minute. As the engine begins to fire, its speed will be much higher than 200 revolutions per minute, and the starting motor, being no longer needed, should automatically disconnect itself from the shaft, since the very high speed at which it would revolve would destroy it by the power of the centrifugal force exerted.

The usual methods of associating one revolving member with another for temporary connections is accomplished by various types of clutches. Those used most frequently, where the self-starting mechanism is employed, are: friction clutches; jaw clutches; roller overrunning clutches; Bendix drives, and electrically and mechanically operated pinions. In every case, however, since the machinery is subjected to the use of operators not skilled in mechanical lines, the devices should be foolproof and free from fragile construction.

If frequent starting demand is made upon the storage battery and relatively few and short drives intervene, where the battery could recharge and become resuscitated, special attention must be paid to the battery. If more energy is taken from such a

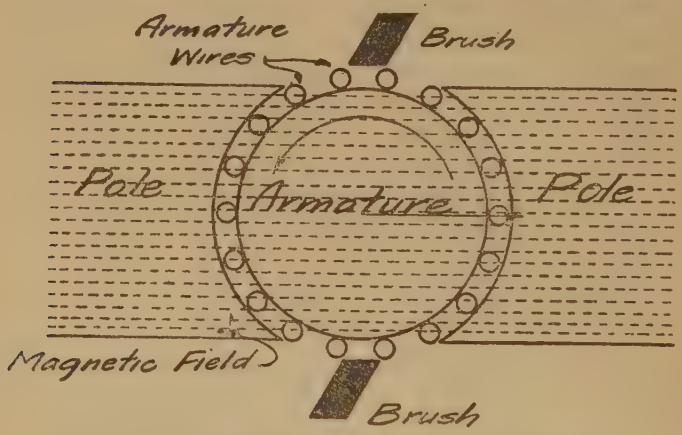


FIG. 168.—MAGNETISM DUE TO MAIN FIELDS ONLY

battery than is put into it, it will certainly be ruined and fail possibly at some critical period. It may be necessary with this type of usage to charge the battery while it is stored in the garage at night, or to give it other protective and preventive attention to avoid complete exhaustion. The charge may be controlled by regulating the output of the generating unit. This in turn depends essentially upon the speed of the engine.

GENERATOR OUTPUT REGULATION

It has been pointed out in previous chapters that the voltage of a generating unit depends essentially upon speed—the other factors remaining the same. As the engine speed varies widely from very low

values to tremendously high values, the voltage and, therefore, output also varies in proportion with the speed. Such a relation, however, does not work to the most efficient service of the machine and some form of control must be employed in order that the output of the generator may increase only to a safe and predetermined value. A very common way of accomplishing such regulation is by means of the inherent characteristics of the machine itself. Such regulation is effected by the so-called *third-brush method,* which will be explained in detail.

The third-brush method depends upon a phenomenon of electrical generator action known as *arma-*

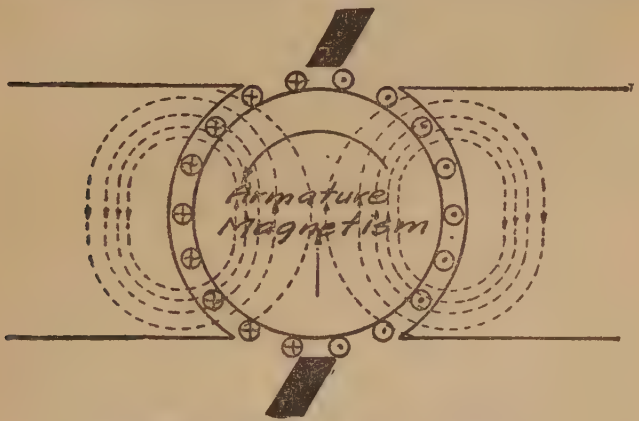


FIG. 169.—MAGNETISM DUE TO CURRENT IN ARMATURE ONLY

ture reaction. Reference to Figure 168 will show that if no current is flowing through the armature circuit, the magnetic field will flow through the armature iron in passing from one pole to the other without disturbance or any distorting effect. On the other hand, consider Figure 169 where, let us

assume, there is no field magnetism produced from the poles at all and that now there is current passing through the conductors of the armature. In this case a magnetic field is set up as shown, which varies in strength and effect, depending upon the value of the current passing through the armature. In an operating generator, however, the combined

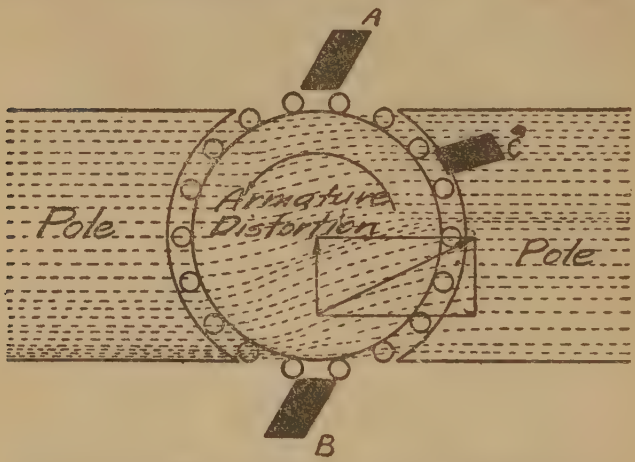


FIG. 170.—RESULTANT FIELD DUE TO MAIN FIELD AND ARMATURE CURRENT—ARMATURE REACTION

effect of the main field magnetism and the armature current field effect is shown in the third figure of this series, Figure 170. In this, the resulting field is seen to sweep not directly across, except in the case when no current flows from the machine, but rather in an oblique direction. This shifting of the resultant field becomes greater and greater as the current flow becomes greater and greater through the armature. This distortion of the combined armature and main magnetic fields is called *armature reaction.*

Use is made of this phenomenon in order to regulate the output of the generator and to keep it constant despite the excessive increases of speed that may result from fast driving. The regulation is effected in the following manner: Let the shunt field of this generator obtain its current flow from brush "A" and the third brush "C." The voltage obtained across these two brushes depends directly upon the number of lines of force cut per second by the conductors that are in series from one brush to the other. It is obvious from the figure that if there is no distortion of the field there will be a higher voltage between brushes "A" and "C" than when the resultant field is shifted in the direction of rotation; since, in this latter case, the field in the space between these two brushes is greatly diminished. Therefore, when being driven as the car increases in speed, the generator will rotate faster and faster, and its current output will tend to increase. This, however, causes a shifting of the magnetic field, thereby lowering the generated voltage. This decreased voltage effect acts to decrease the current slightly. Or, in other words, the weakening of the field takes place in about the same proportion as the speed increases and the voltage, therefore, remains about constant with a resulting constancy of current output. If the third brush "C" is moved nearer to brush "A," the current charging rate for the storage battery will be at a higher speed. Such a setting would be desirable when the car is being operated on long runs at high speed. In the case cited previously, where heavy and frequent starting is required, the third brush should be moved farther away from brush "A," thereby giving a greater voltage and a larger charging current. The brush is

made movable in this way for purposes of adjustment to special conditions.

THERMOSTATIC REGULATOR

Instead of the type of regulation just described, where an inherent characteristic of the generator is used in order to secure the necessary regulation of the output current for the storage battery, the thermostatic regulator as an auxiliary device may be used for that purpose. It consists of a system of contacts formed at the ends of springs. These are made of stripes of brass and nickel steel welded together and which with the contacts form a part of the electric circuit. Normally, the tension of the springs acts to keep the contacts closed; but as the current becomes excessive it heats the springs. Now, the heating causes the brass to expand more rapidly than the steel and, therefore, the spring finally warps sufficiently to open the contact. In so doing, a certain amount of resistance is inserted, in series with the shunt field. This resistance reduces the magnetism and in consequence also the generated voltage, and, therefore, current.

If the speed increases still further, another set of contacts opens and inserts still more resistance into the field circuit. There are usually four sets of contacts that operate in this way and that are quite sensitive to the heat changes that accompany the various values of current. This is an automatic way of accomplishing the same regulation as would be done on any generator by a manipulation of the field rheostat.

RELAY REGULATOR

A most ingenious mechanical device was constructed to give the desired regulation of the gener-

ator output. It is constituted of a *cut-out, relay contacts, regulator contacts* and an *electromagnetic* system for the contact operation. The electrical circuits are shown in Figure 171. The opera-

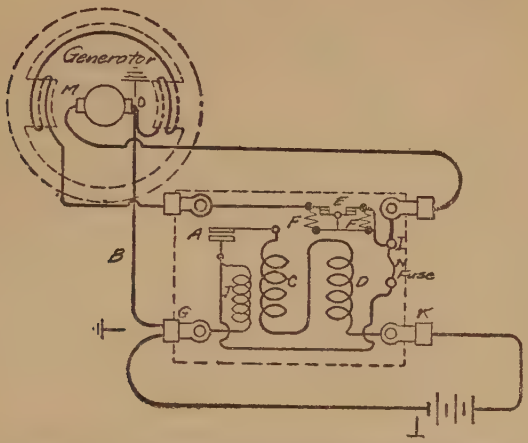


FIG. 171.—METHOD OF VOLTAGE REGULATION ON AUTOMOBILE GENERATORS

tion of the relay regulator in conjunction with the generator is as follows:

First, as the engine starts and runs slowly, output relay contacts at "A" are open, and the main vibrator contacts at "E" are closed. The main lines from the brushes pass in order from "M" to "I." The current divides here, a small exciting current flowing through contacts "E," the poles, and to the other side of the armature brush "C." The main current flows from "I" through fuse "N" to relay contact "A," which, being open, causes the flow to pass through the coil "J" and back to "O."

Second, as the car or engine speed increases, the current through the circuit increases until finally

the coil "J" becomes strong enough magnetically to pull down the upper contact of "A" and close the circuit for the main coils "C" and "D." The main current from brush "M" now flows to "I," "N," "A," "C," "D" to the storage battery and back to brush "O." The magnetism of coil "C" helps to keep contact "A" closed. As the charging current increases to a certain predetermined value, the magnetism of coil "D" draws down the main regulator contacts at "E." The field current therefore must pass through the resistance "F." The field is thereby weakened and the charging current is consequently reduced, a condition which, in turn, weakens the magnetism of coil "D" and permits the contacts "E" to close. This process of rapidly weakening and strengthening the current in the shunt field continues. The current output of the generator is kept at a relatively constant value.

Third, as the car speed decreases the regulator contacts close and remain so as long as the current value is below the maximum output. At the low speeds where the voltage generated by the generator becomes lower than the battery, the relay contacts open at "A" thereby prohibiting a discharge of the battery through the generator.

This type of regulation gives most satisfactory results. The device is rugged and requires almost no attention. At periods of at least two months it is advisable to remove the cover and run a strip of number 00 sandpaper over the contact points in order to reduce any rough surface that has resulted from the constant sparking that there occurs. After sandpapering, a piece of plain white paper should be run through to remove any dirt or grit that may have accumulated during the process.

CHAPTER VII

ELECTRIC METERS

IN all the great fields of science there are characteristic quantities that require measurement. For example, in civil engineering, the angles and distances bounding some particular territory must be measured or the curves of a railroad laid out for construction. In the field of steam engineering, the pressure of the steam in the boiler must be known and the quality of this steam as it passes into the engine should be ascertained—does it contain considerable moisture or is it relatively free from moisture and called "dry steam." The quantity of steam and the horsepower of the engine, too, require measurement. In a store, the clerk must apply one measure and another in order to supply the demands of the customers as they give their orders—at one time it is a gallon of something, at another time a pound. In some of the extremely accurate measurements of physical quantities, time must be recorded not to the second or one-fifth of a second, but more often to the one-thousandth or even one ten-thousandth part of the second. Lengths likewise are measured by the micrometer to the one ten-thousandth of the inch. Pressures and weights are measured to similar degrees of precision. This is true in each field of activity. The accurate measuring or metering of certain quantities is essential

for the purpose of perhaps sale or for information to assist in experimental work. The measurements of all the characteristics that enter into the activities of the entire world may be classified under the three general divisions of length, mass and time. Of course, we have many measurements which, at first thought, one would not classify under any of these headings, but closer analysis shows that such divisions are in reality derived from the above fundamentals.

This condition also prevails in the electrical field. Here, too, precise measurements are required and instruments and meters are necessary in order to give such information. In no other field can measurements of the respective quantities be made with the marvelous accuracy and precision possible in electrical work. The electric current which heretofore was mentioned in terms of hundreds, thousands or perhaps in even greater numbers of amperes may be detected and measured accurately by the supersensitive meters, now in use, to as small as one one-hundred-millionth of an ampere. To the same degree of precision may the units of pressure, power, and energy be measured. So flexible is the system of measurement that in many cases the same instrument, by a ready conversion, will serve in the measurement of either current or pressure. Even the small boy of to-day speaks the names volts, amperes, watts, and the like with some degree of apprehension. When the youthful manipulator of his home-made wireless equipment goes to the hardware store for a dry cell, you mark his shrewdness in demanding the clerk to test the cell by his pocket ammeter to ascertain whether it indicates the average condition of twenty-five am-

peres. The man who labors day by day in the tilling of the fields or in the common labors of life's walk, exhibits an example of knowledge and economics as he steps into the electric store and calls for a Mazda lamp. He knows to a remarkable degree of certainty what he wants. The clerk cannot induce him to buy a 75-watt lamp because he knows that 40-watt size will give about enough light and that it costs less to operate. In this he appreciates the necessity of avoiding an excessive degree of illumination. It is fortunately becoming a matter of common knowledge that people have their eyes subjected to strain more often from too much artificial light than from too little.

The manager of the average industrial plant seems to be surprisingly aware of the economies involved in the choice of the proper sizes of motors for his particular needs. He consults with a reliable electrical man, weighs the matter in the balances of his own judgment and then passes the final word. Practically all of these common cases involve the knowledge and use of units that are subject to direct measurement. Meters of various kinds may be employed to indicate volts, amperes, watts, watt-hours, ohms, and power factor. Measurements may also be employed more or less directly to measure units of inductance and capacity. These latter measurements are rather involved and since they affect only the activities of scientific investigation, it is a matter that comes only to the attention of the experts in this electrical field.

As the pressure gauge registers the energy pent up in the pipe of water or steam, so does the voltmeter indicate the presence of electricity existing between any two points of the electrical circuit. As

the potential difference between any two wires or any two points of an electrical circuit is desired, a voltmeter must be connected across these points. It must be most emphatically impressed upon the memory of the operator that the *voltmeter should be connected so that its two terminals are across the circuit.* In reality this one statement, if properly grasped and conceived will help to clear the meaning and operation of all these meters. The fundamental operation of all types of meters depends directly upon the principle of the motor already explained in the chapter on the electric motor. There is a magnetic field and an armature which carries a current and reacts in such a way that motion results. Indicating instruments have springs that so oppose the tendency of rotation that the deflection of the armature, to which is attached a long needle that swings over a marked scale, is proportional to the affecting function, be it voltage, current, or watts. *The elementary principle of every meter is that of the electric motor.* First, let us take up in detail the voltmeter for measuring pressure in a direct current and in an alternating current system.

The fundamental operating characteristics that actuate voltmeters may be divided into the following general classes, which apply to the direct or alternating current systems as indicated.

1. Permanent field-magnet and moving-coil type for use only for direct current measurements.

2. Fixed field coil and moving magnetic vane type applicable to either direct current or alternating current voltage measurements; but must be tested and the scale marked for one or the other only.

3. Hot-wire voltmeter type. Equally applicable and accurate measurement on either alternating or direct current systems.

4. Electrostatic voltmeter type. For use only on high voltage work and is equally applicable to either direct or alternating current work.

PERMANENT FIELD MAGNET AND MOVING COIL TYPE OR D'ARSONVAL TYPE VOLTMETER

In most extensive use and perhaps most accurate of all meters for indicating voltage is that of the

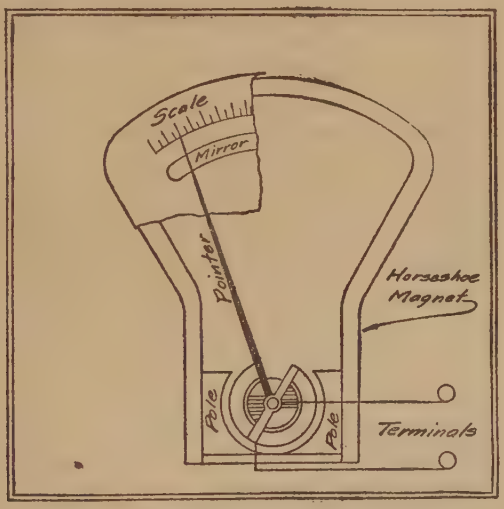


FIG. 172.—PERMANENT MAGNET MOVING COIL TYPE METER

permanent horseshoe magnet type having a moving coil for actuating the needle over the scale in proportion to the magnitude of the force acting. A simple diagram to show the parts of such a system may be seen in Figure 172. The poles of the

permanent horseshoe magnet terminate in the soft iron pole shoes which are curved concentrically to a soft highly magnetic cylindrical core, located between the poles. Between the poles and this core is a narrow air gap space uniform throughout in which a very light thin coil of wire is so mounted that it is free to turn. The axis of the coil is supported by jeweled bearings and current is led into and out of this coil through helical springs, one mounted above the coil and one below. As current passes through the many turns of this coil, a magnetic field is set up about the coil that reacts upon the permanent magnetic field and produces the motor action that causes the coil to move in a clockwise direction. This movement causes the springs to wind up and, therefore, oppose the motion of the electrodynamic action. By properly designing the relations of these parts, the needle which is attached to the moving coil may be made to move over the scale just twice the distance for two times the current through the coil, and three times the unit distance for three times the current. In other words, the scale may be made with uniform spacing of the marks indicating volts. As the moving coil moves in response to the motor action, it always remains in a permanent field of uniform value, so that the resultant force and, therefore, the motion changes in the identical proportion that the current through the moving coil changes.

It is to be noticed that this type of instrument is positive in its motion. By this we mean that it must operate from the zero of the scale in one direction only due to the fact that the current flows through the coil in a certain direction. Care must be taken that the meter is not connected across the

circuit in the reverse direction, so that the current flows in the opposite direction or else the needle is caused to slap back against a stop and may become bent. Figure 173 shows how a voltmeter should be connected across a circuit to measure the voltage from point "A" to point "B" in each case. The two terminals of the meter are marked one positive

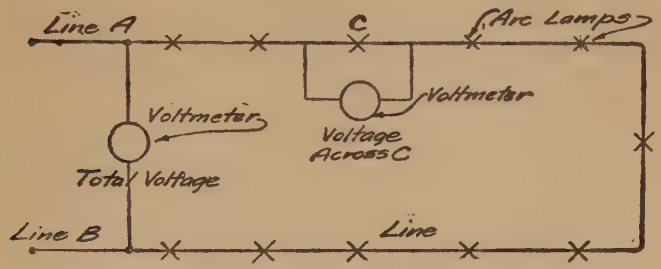


FIG. 173.—CONNECTIONS FOR VOLTMETERS TO A CIRCUIT

(+) and the other negative (—) to indicate which should be connected to the positive and negative sides of the line respectively.

You may ask why this meter will indicate volts across the line when during the explanation of its action we have shown that current flows through the moving coil whereby its motion is derived. Ohm's law will readily supply the answer to this query. The electrical circuit from the one terminal of the meter to the other includes not only the light moving coil but also a coil of resistance wire having many thousands of ohms of resistance, in order that the current which flows through this circuit may be very small. It is customary with one of the leading manufacturers of such meters to use about one hundred ohms of resistance for each volt of scale reading for which the meter is designed. That

is, a 150-volt voltmeter would have approximately 15,000 ohms. This means that only about one one-hundredth of an ampere is permitted to flow through the circuit to produce the maximum deflection. Suppose for instance, that this 150-volt voltmeter were used to measure about 25 volts, then only one six-hundredth of an ampere would flow through this meter, but the electromagnetic action causes the needle to move until the exact voltage is indicated. If now the voltmeter is connected to a 50-volt circuit, just twice the current would flow which would react with the constant and permanent field strength to give just twice the force and resultant deflection. Therefore, the needle would move twice the distance over the scale. That is, the resistance of the circuit is constant, consequently the current varies exactly in proportion to the volts impressed across its terminals. Furthermore, since the magnetic field strength is constant, the motor effect or moving force varies exactly as does the current through the coil.

This type of meter is most satisfactory and popular for many reasons, among which are the following important and salient ones:

1. The scale has uniform divisions, which facilitates easy and accurate reading.

2. It is least affected by any stray magnetic fields from adjacent wires and circuits.

3. It is "dead-beat," that is, it comes to rest at the proper indication almost immediately.

4. It holds its calibration, that is, correctness of markings for relatively long periods.

5. It may be made very rugged to withstand the hard usage of portable service and still maintain its accuracy.

The feature alluded to as the "dead-beat" characteristic is one of great importance in the general use of any meter. It is most unsatisfactory in using a meter to be compelled to wait for the needle to cease swinging when the connecting switch is depressed. A meter that has the "dead-beat" quality in its moving system immediately comes to rest at the proper value instead of oscillating about that mean position for several seconds. This *damping effect* to render the desirable "dead-beat" quality may be accomplished in practice by two general methods, one by the use of little air vanes acting in a closed air box, thereby opposing the motion, and the other by employing the principles of *magnet braking*. The latter method is by all means best where the constructional features permit. In the case of the type of meter under discussion, the *magnetic damping* is employed. The coil of the moving element is mounted upon an aluminum rectangular backing. As the coil moves in this strong magnetic field, this aluminum rectangle acts as one turn of wire, constituting a closed circuit having a relatively very large cross section and therefore low resistance. Consequently, a current is produced of relatively large proportions which opposes the motion of the coil by virtue of its reaction with the magnetic field. Such damping is very effective.

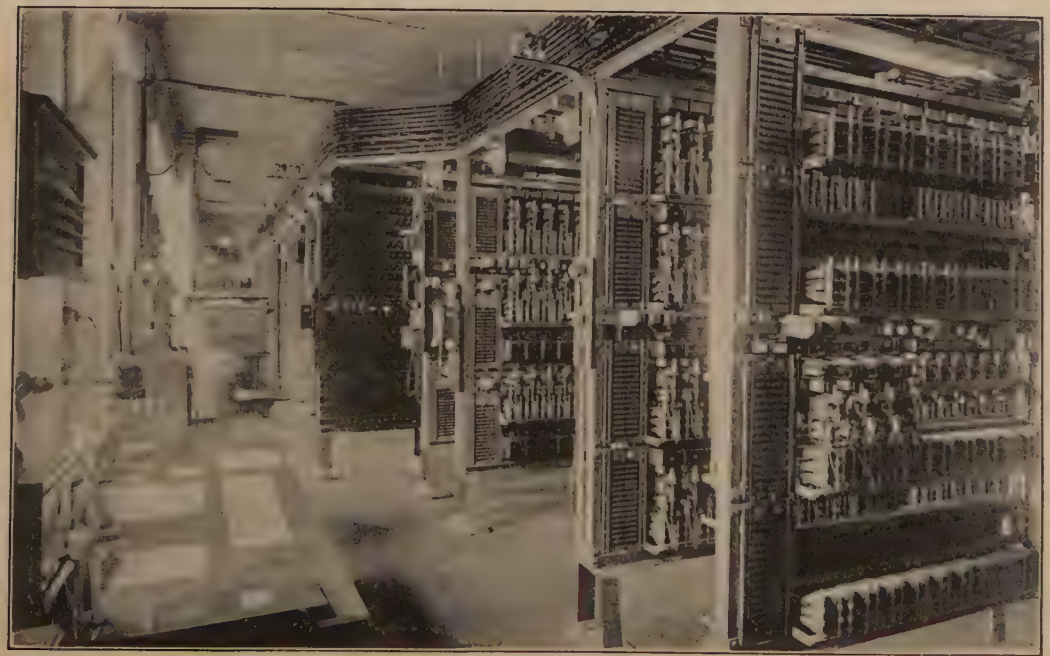
The horseshoe magnets employed in the manufacture of these meters are constructed of the finest grade steel, thoroughly magnetized and *aged by artificial means* so that the strength of the magnet will not change more than a minimum amount over a long period of years. The use of the soft iron cylinder between the poles serves to reduce the reluctance of the path of the magnetism and to

create a uniform magnetic field. This field has a high density, or in other words, the air gap is highly magnetized. Therefore, the effect of the magnetism due to adjacent pieces of iron lying in the vicinity of the meter has a minimum effect in disturbing the quality and quantity of this field either by adding to or subtracting from it. The meter case is made of a magnetic substance in order further to shield the air-gap magnetism from the effect of any stray magnetic field. Naturally the stronger the acting field of the meter is, the less would be the disturbing influence of any stray field and, in consequence, the more reliable will be the operation and registration of the meter.

All indicating meters for accurate work should be provided with a mirror band under scale as shown in Figure 175 to assist in the correct reading of the scale and to avoid the errors of parallax. To read the indications of the meter properly one should look down upon the needle so that its reflection in the mirror will be exactly covered by the needle itself and then observe the reading of the scale under the needle.

FIXED COIL AND MOVING MAGNETIC VANE TYPE VOLTMETER

Many of the cheaply constructed meters on the market to-day, of which some give very good results, employ a certain form of iron vane which is actuated by the influence of the magnetic field acting upon it. Such meters are grouped under the general heading of *magnetic vane type meters.* The fixed coil is connected through a high protective resistance across the line as any voltmeter. The current which flows through this coil sets up a mag-



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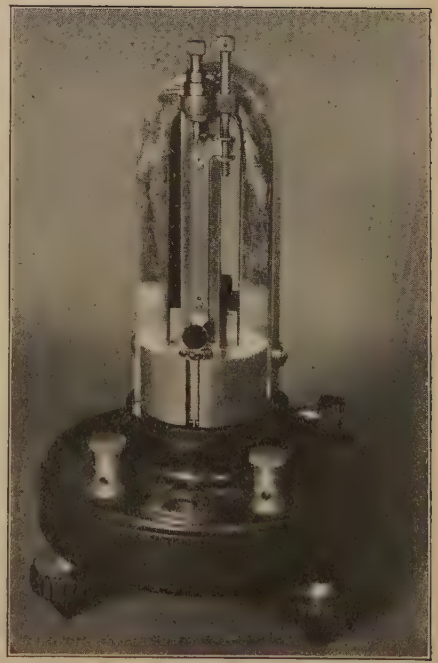
AUTOMATIC TELEPHONE EXCHANGE IN GERMANY



Photos, Leeds & Northrup Co.

THE D'ARSONVAL GALVANOMETER

The view at the right shows the mechanism with the outer case removed.

netic field which is practically proportional to that current. Within the coil a light iron vane is mounted upon an axis supported by jeweled bearings. The axis of the coil and the axis of the vane are not coincident but rather at such an angle to each other that, as the magnetic field increases, the iron vane has a tendency to turn so that an easier path is presented to the passage of the lines of magnetism. This motion is regulated so that it is proportional to a function of the current passing through this fixed field coil. The scale is marked to

FIG. 174.—TYPE OF UNIFORMLY DIVIDED SCALE ON ALL D'ARSONVAL METERS

record correctly the volts. A meter of this type may be used either on direct or alternating current, but if it is tested and calibrated for alternating current it cannot be employed to give accurate results on direct current, until it has been recalibrated on a direct current system. These meters are used most extensively on alternating current since they are quite accurate, relatively cheap, most rugged in their construction, and require a minimum of attention.

The scales of such meters do not have the convenience of the uniform divisions that the permanent magnet type meters have. The divisions are very closely congested toward the lower end of the scale and render the reading difficult and the pre-

cision unreliable. No voltmeter that is designed for use on an alternating current system can have a uniformly divided scale because of the fundamental principle involved. The *motor turning effect* is always produced by the product of the magnetism of the field and of the moving system. Now, in this case the coil (fixed) produces a certain strength of magnetism which in turn magnetizes the iron vane. The magnetism of the iron vane is nearly proportional to the current in the coil. The field that sur-

FIG. 175.—TYPICAL SCALE FOR A. C. METERS. PARABOLIC TYPE OF SCALE

rounds the coil is about proportional to the current in that coil, and therefore the torque or motor turning effort which operates the moving vane is proportional approximately to the square of the current in the coil, that is, the product of the current by itself. You may remember that in the permanent magnet type the torque changed exactly in proportion to the current in the moving coil, since the field magnetism was of a fixed and permanent value. This means that a scale of uniform divisions is a characteristic of the permanent magnet type, whereas the nonuniform type of scale is characteristic of the magnetic vane type of meter. Such a type of scale is shown in Figure 175. Small meters of this type are used quite commonly on the storage battery charging sets in garages where mercury

converters are employed. Automobiles, likewise, use this type of meter extensively because of the ruggedness of its construction.

HOT-WIRE VOLTMETER

This type of meter is not now used extensively as a voltmeter, although at one time in the earlier days of meters it was quite generally employed.

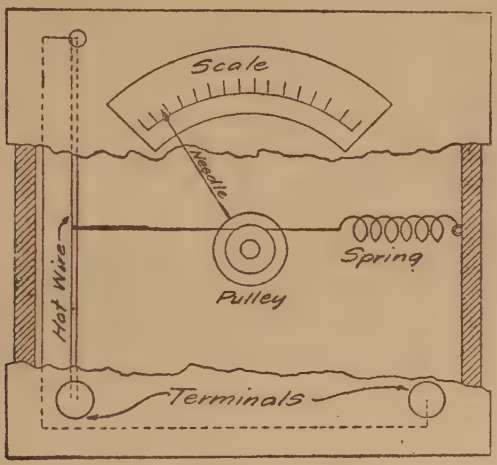


FIG. 176.—SCHEMATIC DIAGRAM OF A HOT-WIRE METER

The hot-wire ammeter, however, finds abundant application in wireless communication work, and in the other places where the current fluctuates too rapidly to permit of accurate reading by the previously described types. Figure 176 shows the fundamental parts involved in the operation of a hot-wire meter. The only difference between the voltmeter and the ammeter is that large currents may flow in the ammeter, but that a protective re-

sistance limits the current flow in the case of the voltmeter. As the current flows through the long wire, it becomes heated because of the current flow and the wire is caused to expand in length—a physical characteristic of nearly every known substance. The retractile spring as it operates to take up the slack in this long hot wire causes, through the medium of pulleys, the needle to move over its scale. Such a meter does not record instantaneous variations in the current passing through it, since appreciable time is required for the heat to cause the necessary expansion of the wire. The meter does indicate, however, an average condition in a circuit where the voltage or current constantly fluctuates as it does in such an instance as a wireless circuit. For such conditions the hot-wire meter is well adapted. The one serious objection to it is that, as the ambient or surrounding temperature changes, the zero setting of the meter is affected and must therefore be readjusted by means of a small adjusting thumb screw. This meter has a scale marked in divisions that are nonuniformly spaced somewhat similar to the scale of the magnetic vane type. It reads correctly on either direct or alternating current, a fact which is greatly in its favor. In general, however, its utility has practically ceased except in connection with radio work. For other usage it has been replaced by much superior types.

ELECTROSTATIC VOLTMETERS

Direct current voltages above 600 volts are not in general encountered except in some of the present new developments of railway service, where it may run as high as 3,000 volts. For such purposes the

permanent magnet type meters may be employed to give entire satisfaction. The only difference between a 150-volt voltmeter and one to measure 3,000 volts lies in the amount of resistance that must be used in order to protect the operating coil and to keep the current to the low value required. To indicate alternating current voltages of high values, meters of the ordinary type with resistance for protection are not satisfactory. It is a customary practice to use so-called *instrument transformers* to step down in some accurate proportion the high voltage to a value that may be read upon a 150-volt voltmeter. This indication of high voltage may also be accomplished directly by employing the attraction of two oppositely charged plates which are insulated from each other by air. One is fixed and the other is free to move and has a needle attached to it for indicating purposes. These plates may, however, be immersed in oil for additional insulating purposes. They are not generally used, however, since most switchboards now in practice have only low potential employed on the front of the board and keep the dangerously high voltage mains isolated in separate compartments. Instrument transformers are in this case used as a medium between the high-tension system and the low-tension meters on the switchboard, an accurate ratio between the two being known.

AMMETERS

The use of ammeters in electrical work is necessary in order to ascertain how much current flows in a line. The use of a voltmeter and an ammeter for any part of a circuit tells the complete story about that part. By Ohm's law we may divide the volts by the amperes and learn how many ohms of

resistance that part of the circuit has. Or we may multiply the volts and amperes together and find the watts being consumed. The ammeter gives the rate of flow of the electricity along the circuit. It is as important in the electrical system as is the

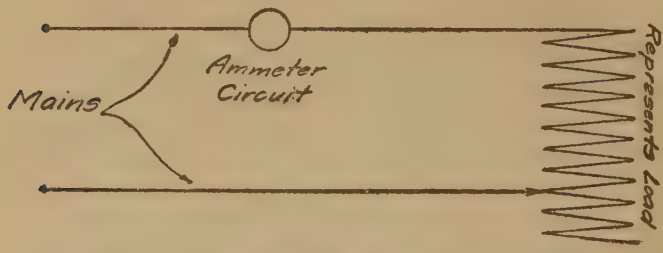


FIG. 177.—CONNECTION ON AN AMMETER IN THE CIRCUIT

gallon measure in the paint store or the graduated flask in the pharmacist's store.

The general types of ammeters are the following:

1. Permanent magnet moving-coil type, for use only on direct current.

2. Fixed field-coil and moving-coil type, for use on either alternating or direct current.

3. Hot-wire type, used on either direct or alternating current.

4. Magnetic vane type, used on either alternating or direct current which must, however, be recalibrated on each system.

The most important of all is the fact that the resistance of an ammeter must be very low because it must be placed directly in the line in order to measure the line current and all of the current must be passed through it. For the reason of its low resistance, it would be most fatal to place it by mis-

take across a line, as a voltmeter is placed, because the tremendous current would at once flow and the meter would be ruined. The ammeter is connected directly in the line, as shown in Figure 177, and never across the line as a voltmeter is connected.

PERMANENT MAGNET MOVING-COIL TYPE AMMETER

The interior construction of the ammeter and the voltmeter is identical. The two differ only in the auxiliary apparatus and in the manner in which they are connected to the main line. Either within the case of the meter or external to it is a shunt or standard resistance, which is connected into the line where the value of current is to be measured, as shown in Figure 178. The current passes through

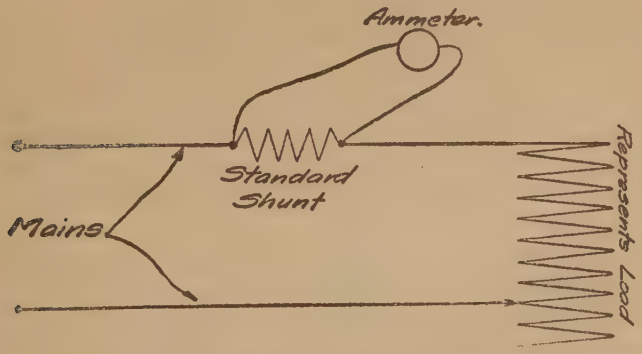


FIG. 178.—USE OF STANDARD SHUNT WITH MILLIVOLT METER AS AN AMMETER

the shunt as through any other part of the line. The terminals of the meter are connected across this shunt and the meter really measures the voltage drop across it. That is, the resistance of the shunt multiplied by the current flowing through the

shunt equals the voltage across it. The meter element measures this voltage. This same meter element may be made into a voltmeter by connecting a high resistance multiplier in series with the meter, as shown in Figure 179. Of course, instead of a scale calibrated in amperes, it would for the latter case be marked in volts. In commercial meters of the smaller sizes the shunts are contained within

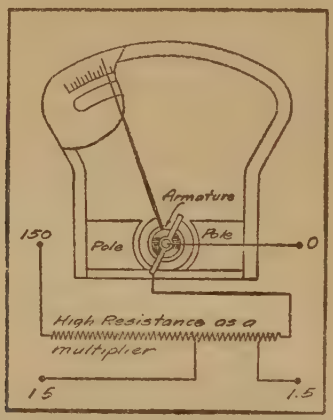


FIG. 179.—A MULTIRANGE VOLTMETER

the case that covers the element; but in sizes above 100 amperes, it is customary to use an external shunt. In reality the meter element of the permanent magnet type is really a voltmeter that reads millivolts. The millivolt is one one-thousandth part of a volt. One prominent meter company makes the meter element so that it gives full scale reading when 50 millivolts are impressed across its terminals. When used with a 10-ampere shunt, it will give full scale reading when 10 amperes flow through the shunt. If it is desired to measure

a large current such as 90 amperes, for example, a 100-ampere standard shunt might be employed, in which case full scale reading on the meter element would result when exactly 100 amperes passed through the shunt. Thereby a wide variety of currents may be measured by one meter through the available variety of shunts. Shunts may be made to record many thousands of amperes which may be indicated upon the same type of meter used to indicate the small current from a dry cell. Practically all switchboard direct-current meters are of the permanent magnet type with an external shunt.

FIXED FIELD-COIL AND MOVING-COIL TYPE—ELECTRODYNAMOMETER TYPE VOLTMETER

This type of ammeter, as the type name indicates, employs, instead of the permanent horseshoe magnet, the electromagnet for its field. There is, however, no magnetic material whatever employed in the construction of this type of meter. The field of magnetic force set up by the current flowing through this fixed coil is exactly proportional to the current. The same is true of the magnetism set up by the current flowing through the moving coil. These two coils are energized by the same current since they are connected in series and, therefore, the force that produces the motion varies at a rate proportional to the product of the current in the two coils. This type of meter has been in use for many years and is the only one now in use that gives high precision operation on either direct or alternating current circuits, and where the scale when calibrated and marked for direct current also indicates correctly on alternating current. The fact that this operation is equally applicable on either direct or alter-

nating current can best and most conclusively be shown by employing Figure 180. Here "A" shows a field of magnetism N and S with a coil of wire located in it as in a simple elementary type of motor. If a current flows in this coil as shown, the tendency of the motor action is to rotate the coil in a clockwise direction. If the direction of the magnetic field and the current through the coil both reverse, then, by the right-hand rule, the rotation still remains in the clockwise direction. When the fixed

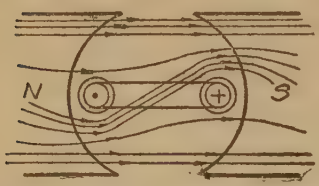


FIG. 180A. — TORQUE ACTING ON METER COIL TENDING TO PRODUCE ROTATION

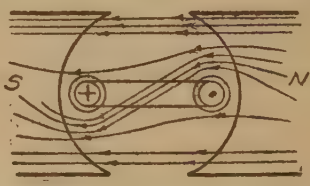


FIG. 180B. — FIELD AND CURRENT REVERSED GIVE SAME DIRECTION OF TORQUE

field coil and moving coil type meter are used on alternating-current circuits, the above process actually takes place. The magnetic field and the current through the moving coil reverse on every alternation, but the torque or motor action remains in the same direction, and therefore registers the indication correctly. The current is led into and out of the moving coil by means of the helical springs.

The moving coil actuates directly the thin lightly-constructed needle that sweeps over the scale and mirror. These meters and, in fact, every ammeter that may be used on alternating current cannot have a scale of uniform divisions. The indications in general are huddled closely together at the low reading end of the scale, then spread out with more

space between them at the middle portion and perhaps become closer together again at the high end of the scale.

Figure 175 showed a typical alternating current meter scale. A meter having a scale with such non-uniform divisions is, of course, undesirable. There seems to be no way, however, of escaping the necessity of this type since the force acting between the two elements (one stationary and one moving) is proportional not to the current directly, but rather to some higher function of the current as, for example, the product of the current in one coil by that in the other. Meters of this type cannot carry currents of large value, since the method of leading this current in and out of the moving coil would become cumbersome and impair the accuracy of its induction. Therefore, this type in practice is limited in its design and operation to voltage measurement where the current required in the movable coil may be very small—just sufficiently large to create the necessary torque. This limits its use, therefore, to the measurement of voltage and power. As a voltmeter the fixed and movable coils are connected in series as just described. As a wattmeter for indicating power, the fixed coil is employed to carry the line current and the movable coil is placed across the line wires with a suitable series resistance sufficiently large to reduce the current through this coil to the small value as employed in any voltmeter.

MAGNETIC VANE TYPE AMMETER

This type of meter has the same general construction as that of the voltmeter already described. The terminals, of course, are heavy on the ammeter and the current-carrying coil must be made of wire

heavy enough to carry the full rated current. For example, a 100-ampere ammeter will have a coil of a few turns of very heavy wire to set up the necessary magnetism. Like any ammeter, it must be connected directly in the line and not across the circuit. No shunt can be employed with meters for use in alternating current, since the difference of inductance of the shunt and the meter element will cause unequal divisions of current for frequencies other than the normal value for which the meter is designed. This type of meter is extensively used in alternating current measurements for testing purposes and for switchboards.

WATTMETERS

The wattmeter is a device made to indicate the power used by any piece of apparatus for any part of a circuit. It is an indicating device and gives the reading at the instant considered, which changes as the load changes. For direct current it reads the instantaneous product of the amperes and the volts. In the alternating current circuit, the wattmeter indicates the product of the volts, amperes, and the power factor.

The most common type of wattmeter is the so-called *electro-dynamometer type* or *fixed and moving coil type*. The fixed coil carries the line current by being inserted into the line as any ammeter would be. The potential is applied to the terminals that connect to the moving coil through the medium of the two helical springs. This coil is made of very light construction and is mounted on an axis supported by jeweled bearings. This coil supports and actuates the needle. The current coil which supplies the field, as in any electromagnet, produces a

field strength proportional exactly to the current demanded by the system, there being no iron in this construction. The potential coil has a field strength exactly proportional to the volts across the circuit and reacts with the field of the current or ammeter

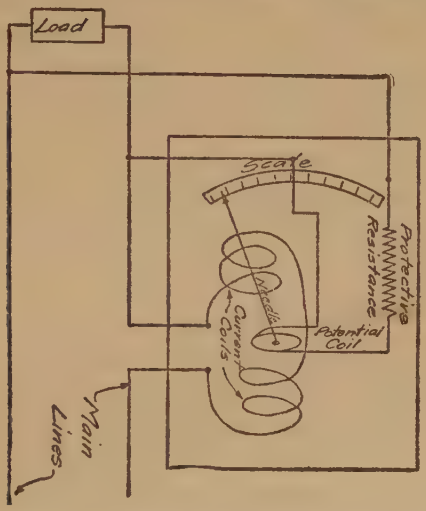


FIG. 181.—SIMPLIFIED DIAGRAM OF AN INDICATING VOLTMETER

element. The resultant deflection of the needle is proportional to the watts and the scale may be so calibrated. The meter may be employed either on alternating or on direct current, although, generally speaking, wattmeters are employed only on alternating current as the product of the volts and the amperes on the direct current circuit gives the correct value of power.

Figure 181 shows how the current and potential coils are relatively related to each other. As any voltmeter element, the voltmeter coil has several

thousand ohms of resistance in series with it. The meter has two heavy current terminals and two potential terminals. Most of these wattmeters have a button that opens a switch so that the instrument indicates only while the button is depressed. The scale is not uniformly divided, but does not in general depart from uniformity to the same extent that those of the ammeter and voltmeter do. A narrow mirror is mounted concentrically with the scale in order to avoid parallax.

Meters of this kind may be found on practically every electric switchboard. They are used to indicate at a glance the amount of power being consumed by feeder circuits and generating units.

WATTHOUR AND HOUSE METERS

One of the best and most extensively used meters on the market is known as the *watthour* or *house meter*. This device is more than a wattmeter, which indicates only the rate at which energy is being expended. The watthour meter combines an element of time with the power which records the actual expenditure of energy. These meters usually record the consumption of energy used in kilowatt hours. In the home where electricity serves to give illumination, to do auxiliary heating, light cooking and other functions, the meter installed by the electric company records by means of a dial system just the amount of energy consumed. This energy may be purchased at about ten cents per kilowatt hour. Many companies in order to encourage the use of electric range cooking make special rates as three to five cents per kilowatt hour. For such use a separate watthour meter must be installed to record the energy used at this special rate.

Figure 182 shows the essential parts of a direct-current watthour meter. In every case, however, the meters consist of a motor element and a dynamic brake element, such as a generator. The motor element is associated with the lines that supply energy to the machinery. There are field coils and an armature. There is this distinct difference in the meter,

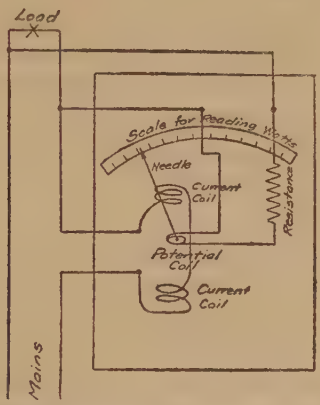


FIG. 182.—SIMPLE VOLTMETER WIRING DIAGRAM

however, to the ordinary motor: In the meter the main line current, which may be large in value, passes through the field coils and the armature is shunted across the line with a high resistance in series to limit the current to a very small value. Of course, the reason for this inversion is that the rotating element should be as light as possible, a condition which can readily be accomplished by using fine wire with a small current. The field coils may be made of wire sufficiently heavy to carry small currents such as ten amperes for ordinary capacity house meters, or even very large to carry

the large currents for big installations. For very large meters a shunt may be employed and a correction applied to its reading to give the true kilowatt hours.

A small amount of energy always flows through the armature circuit, but the field is energized only when the system is loaded. This field current magnetism reacts with the armature magnetism, and causes rotation in any motor. The more current that flows through the field, the faster will the armature turn. Geared from the upper end of the armature shaft or axis is a train of accurately designed gears that actuate hands over the dials to record the kilowatt hours 10s, 100s, 1,000s, and 10,000s. There must be a way to make the speed of this motor element proportional to the true kilowatt hours expended. This is accomplished by a unique generating or braking device. To this motor shaft is attached an aluminum disk which revolves between the poles of two or three horseshoe magnets. This disk, of course, as any conductor or wire, cuts the field of magnetism of the magnets and generates a voltage which in turn causes eddy currents to circulate throughout the disk. The effect of this is to oppose the motion of rotation. Exact proportionality between the speed of the meter and the register of kilowatt hours may be established by properly placing the magnets in respect to the center of the disk. The retarding effect of this eddy current generator may therefore be increased by moving the magnets out toward the edge of the rotating disks. The process of adjusting the meter to register correctly entails the proper setting of these magnets. As they lose their strength through jarring and changes of temperature, the meter may in-

crease its speed and register more energy than the customer actully consumes. In most cities the law requires that the meters be tested and corrected at least once in each year. The shaft that carries the armature and aluminum disk is supported in its vertical position by a cup-shaped sapphire or diamond jewel bearing which is mounted on a spring at the base of the meter in order to absorb the energy of any shocks or jars. The meter runs with practically no friction and is thus a most complete little instrument. The commutator and brushes of these meters are made of silver in order to have a minimum of resistance and to reduce the contact fricton to the lowest possible value.

The alternating current watthour meter operates in a way somewhat similar to that of an induction motor. The functioning of its parts resembles that of the direct-current meter. The damping is effected in the same way and the dials record the energy in the same way. Some of these alternating current meters are for use on single-phase systems and others on two and three-phase. Where two and three-phase meters are used, there are two motor elements on the same shaft which operates in such a way that the total energy of the system is recorded on the dials as for a single-phase instrument.

RECORDING METERS

In recent years a system has been devised and put into operation among many of the large power companies to charge extra for any unusual demands of energy that occur during certain hours of the day when the plant is already loaded. In the contract that a customer writes with such a company a clause states the penalty for such overloads at these crit-

ical periods. These peaks of loads on the plant may rise to great values for only a two-hour period of the day. In order to supply this demand, extra machinery must be at hand ready to start when this demand arises, to operate for an hour or so and then be shut down for the remainder of the day. The extra charges of interest, taxes, depreciation and the like for this extra equipment should rightfully be the penance for those who demand this extra power at the time of day that causes disadvantage to the plant. For example, a plant supplying energy to a railway service has abnormal demands for its power during the hours from seven to nine-thirty in the morning and from four-thirty to six in the evening. Customers who require excess energy during these periods must pay more for this privilege.

Consequently, there must be some way of recording the instantaneous demands of these large power consumers. In order to meet these requirements, recording meters such as voltmeters, ammeters, wattmeters, and power factor meters have been made. These operate to give the value of the watts, volts, etc., to the time of day where a clock mechanism continuously moves the paper along. Ink feeds through the meter needle and leaves its record upon the paper.

Since this subject is so very broad and there are an almost infinite number of special meters and instruments that are adaptable to the multitude of applications already in existence, and more that are daily being born into our requirements, any really comprehensive description is here impossible.

In closing, however, we would like to call attention to one of the most delicate meters known to

man which has applications in fields without bounds. This meter may be used as a voltmeter and ammeter for detecting and measuring currents of from ten to one hundred millionth part of that required for the ordinary size of electric light bulb by which one may be reading this print. One of the most accurate and sensitive meters is really a permanent magnet moving-coil type meter, but differs from those of this type as previously explained chiefly in the manner in which the coil is supported. In this meter, which is called the *galvanometer,* the coil hangs in the narrow air gap suspended by the finest of silver wires, much smaller in diameter than that of the ordinary hair of the head. Attached to this suspension is a small circular mirror. About one yard in front of this mirror and coil is supported a scale formed into the arc of a circle with the mirror as its center. Mounted above this scale is a small telescope having a hair line running vertically through its field of vision. By focusing this telescope upon the mirror, the reflection of the scale may be observed. When the coil has no current flowing through it, and therefore is in its normal position of rest, the zero of the scale should coincide with the hair line of the telescope. As a minute current is passed through the coil for the purpose of measurement, the deflection of the coil may be read upon the scale. This type of construction gives the benefit of a very long pointer without actually having any weight, which would create friction and impair the accuracy and sensitivity of the indications.

CHAPTER VIII

ELECTRIC TRACTION

THE trolley car and the electric train, both slow and high speed type, are now such common sights that we can hardly believe that there was a time when their work was done either by horse or the steam locomotive. At present they are absolute necessities and stand foremost in the rank of electrical achievements. For over thirty years, construction, improvement, and growth has marked this field of electric traction as one of the most progressive in our country. An illustration is seen in the fact that, while at one time the electric motor and the storage batteries used to drive it occupied the greatest part of the available space in the car, now the motors are so fully concealed and the room for the passengers has become so spacious that we seldom give thought to the machinery used to propel the car and much less to its whereabouts.

The electric service of to-day is considered as natural a part of any community as are the trees of the parkway. Their absence rather than their presence makes them conspicuous, and, indeed, a community is poor and unattractive without this cheap and ready means of transit. Practically all cities have a network of lines that permits one to go and come from every important point at a nominal charge. The outlying territories have a system of suburban lines with cars of larger size and higher

speed than those adopted for city use. Then there are long-distance lines called the *interurban systems* that connect together the business, economic and amusement activities by the ties of convenient travel. These transit facilities assure in time the extensive growth and the stability of business and industrial enterprises. The street car systems have thus been a form of public utility that has been a factor of no small significance in expanding and promoting the possibilities of cities and smaller communities. Industry and transportation have been linked together by inseparable bonds. One grows as the other does.

The problem of the feasibility of a proposed electric road is one that involves the consideration, analysis, and prophecy of an experienced engineer. Questions of the future growth of the community, the effect on the industries, the type of residents, the cost of right of way and franchise, the cost of the roadbed, of the rolling stock and power equipment, the estimate of the number of passengers and many other considerations are of vital importance in settling upon any solution relative to the proposed line. In deciding these issues, comparisons of the costs and of the income of roads having similar conditions to meet often furnish the most tangible information.

To-day the subject of electric traction is not restricted to the ordinary street car lines, but it includes as well the elevated lines, the subway systems and the trunk lines and terminal conditions of many of the most powerful railroad systems of the country. It is now a fact of no little importance that steam engines no longer draw their great trains into terminal stations of such cities as New York.

Instead, powerful, swift, silent, and clean electric locomotives meet the terminal requirements with the utmost satisfaction. The points of congestion of traffic and general transportation on our national railroad lines are now being relieved by the installation of electric systems. Such work is accomplished in a way far more economical of fuel and of repair costs than can be done in the case of steam locomotives. Instead of the power for each train being generated in a notoriously poor and inefficiently small individual power house, as each steam locomotive really is, the electrical energy is generated in a most efficient manner in large power houses where every pound of coal must be accounted for, and from there is economically transmitted to the train and there utilized in an efficient manner.

STREET CAR SYSTEMS

For city use direct current is used almost exclusively. The direct-current series motor is the best motor known for traction service. For light loads, such as level track operation, it runs along at high speed and requires very little power, while on heavier and increasing loads it slows down materially, thereby gaining the advantage of a tremendous increase in torque or pulling power for a relatively small increase in current demand from the power house. Furthermore, the direct current motor responds to control with greater ease, less expense of auxiliary apparatus and with greater efficiency than is true of any other type of system. The voltage universally employed for city use is 550 to 600 volts. The motors are connected to the axles of the driving wheels through a single reduction gear, a condition which permits the motor to

operate at an efficient and high speed, yet the car may be always maintained under absolute control.

The spring resilience between the truck and the car body, it will be noted, is obtained by the *floating-bolster construction.* Many of the city cars have a single truck with a short wheel base to enable them to take the sharp curves of the street. Such cars operate at not more than twenty-five miles per hour. The larger cars for suburban service use the double truck cars which have either one or two motors. The single trucks use only one driving motor, which may range from 15 to 30 horsepower.

The motor must be so supported that its gear always centers about the car wheel axle, and thus remains in mesh with the axle gear as the springs supporting the car body give and take under the strains of the rough roadbed. The other end of the motor has a nose which is supported to the framework of the truck. Motors are mounted in this way on most types of trucks for street cars although some are being connected directly to the axle so that the armature shaft becomes a part of the wheel axle. Such construction, called *direct drive,* is used only on high speed service.

Car bodies are made in various designs depending upon the purposes for which they are to be used. Some are made for summer open service, others are wholly closed with windows that may be opened, while still others are semiconvertible and may serve for winter or summer use, since the windows are so built that in winter they may be left closed or in summer may be opened or entirely removed. During the present period, when labor is an expensive and unreliable item, car bodies are being con-

structed of the one-man type. In these, entrance and exit is gained by means of doors placed only at the front near the motorman's seat. In addition to operating the car, he also collects the fares and has full charge of the car, thereby reducing the man cost to about one half per car.

For all cars means of safety to the passengers is of the utmost importance. The pay-as-you-enter car has gained greater popularity for speed of service and safety to the patrons. As the car stops, the door may be opened and a step lowered by the control of the conductor. The patrons enter the vestibule and as the door is closed and the step folded up, no one can either board or leave the car. This precaution eliminates a type of accident that was formerly quite common and which resulted from an attempt to leave the car while it was in motion. In New York City, as well as in a few other cities, the very low-bodied car called "the hobble-skirt" type, has met with popular acclaim because of the ease of access.

Various arrangements of seats have been devised in order to afford the greatest capacity for patrons during rush hours. It is not the custom and in fact it would be an economic error to attempt to seat every passenger during the peak loads of rush hours. The desire of the company is to be able to handle the impatient throngs during rush hours, and during the remainder of the day to relieve the schedule by operating fewer cars, but to be able in general to seat the patrons during off hours.

The motorman has supervision over the devices for controlling the behavior of the car. These are the controller, which contains the electrical contacts for inserting the protective resistance during the start-

ing period and then cutting out these resistance units as the car gains speed. In its operation the motorman must keep the controller handle at the running position when the power is on. The following conditions affecting the power required by the car must also be observed: first, acceleration where large demands of power are necessary; second, the condition of full speed operation, where the power demand is relatively small; third, the period of coasting requires no power and utilizes the kinetic energy of the car; and fourth, the braking process where no electrical energy is demanded and the kinetic energy is dissipated in the form of heat by the friction of the brake shoes against the wheels. The motorman can effect economy in the operation of his car by judicious balance of the coasting against the periods of power demand. In the city where stops are most frequent, motors of relatively large power should be employed so that the acceleration may be rapid in order to get under quick headway and maintain the schedule.

The universal type of brake now used is the air brake which is controlled by a handle of a three-way valve. The normal position permits the handle to be removed if the motorman leaves the car. If the handle is moved in one direction air is admitted from the pressure tank to the brake cylinder which operates the piston to apply the brake shoes. In the other direction the air from the brake cylinder is relieved in order to remove the brake-shoe pressure. A motor operates an air compressor, which stores the air in a reservoir tank until the pressure reaches a predetermined amount, when an automatic switch opens the motor circuit to stop further pumping. When the air pressure is reduced to a certain fixed

minimum value, the pump again starts up and continues until the maximum pressure is again established.

Some of the interurban car lines and particularly those in operation in the Middle West are very large and heavy and employ four motors per car. In starting these cars two of them are placed in series across the line with the starting resistance. Then, as the car accelerates and the starting resistance is all cut out, the next move of the controller handle places the motors in parallel across the line with the starting resistance again in the circuit for protection. As these resistance units are now cut out by moving the controller handle further, the motors are eventually placed directly across the line and operation is established upon the full line voltage. Two or three cars are sometimes operated in trains, where one may be equipped with the luxuries of lounging chairs, buffet, smoking compartments and washrooms similar to the Pullman service of the railway lines.

For the long-distance service required in interurban service, the use of 600 volts direct current is quite insufficient and not economical. Some systems are, therefore, using 1,200 volts for this purpose. Other lines are using high-voltage alternating current single-phase systems. But for trolley-car service it is more customary to transmit the energy by means of alternating current and convert it by substation equipment to either 600 or 1,200 volts direct current for use on the trolley lines.

The method of supplying the electric current to the car in the great majority of cases is by means of the overhead wire, trolley wheel, and pole. Yet in some of the cities the overhead wires are an objection which

is overcome by employing the underground trolley or conduit system. Here there are two third rails, one positive and the other negative, located in a conduit underground between the two rails. The contact is established by means of ploughs that run in a slot between the two rails. In the more general overhead trolley-wire system, the current flows from the power house to the car on the trolley wire, passes down through the pole to the motors, and thence through the wheels to the rails and back to the power house by means of the rails as return conductors. This means a great saving in the investment outlay on the copper, and a convenience of construction. In order to increase the conductivity of the path through the rails, the joints between rails are made electrically conductive by bridging them with flexible copper bonds. In cities it is important to take every precaution to have the rails thoroughly bonded and even to run a return copper feeder between the rails and underground to which the rails are connected at intervals of every few feet in order still further to insure a return path of extremely low resistance. If such is not the case, the resistance of the earth, of adjacent water, gas, and sewer pipes may be found to be considerably less than that of the rails and as a result the current will take these as return conductors to the nearest point of the power house. As the current leaves these pipes, it eats away particles of the iron and soon causes a rupture of the pipe and often considerable damage. This in turn becomes a liability of the electric company which is often followed by expensive litigation and damage suits. Figure 183 shows such a return system by pipe and illustrates where the current leaves the pipe for the power

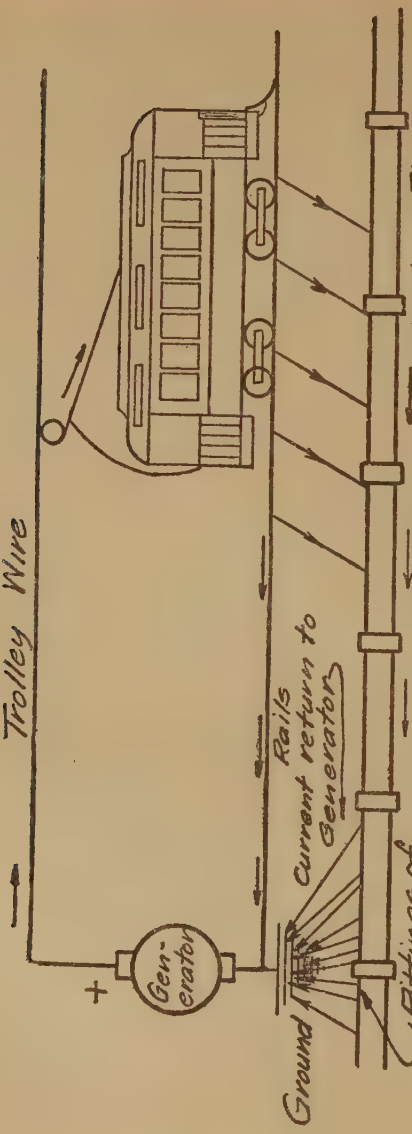


FIG. 183.—ELECTROLYSIS OF WATER PIPES DUE TO STRAY EARTH CURRENTS

house. This process of destruction is called *electrolytic corrosion.* Almost unlimited expense in preventing any such electrolytic corrosion on the part of the electric traction companies is justified since their litigation difficulties are greatly reduced. Figure 184 shows a system where return conductors are run between the rails with frequent connection to the rails in order to reduce the resistance to a minimum.

In the case of the double-conductor underground conduit system the rails do not act as the return system, but this function is performed by the nega-

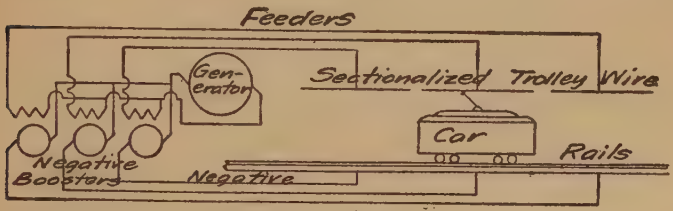


FIG. 184.—SECTIONALIZED TROLLEY WIRE SYSTEM

tive feeder contained in the conduit. This greatly assists in reducing to a minimum troubles resulting from the electrolytic corrosion.

We have learned that whenever current flows through a conductor, a certain amount of voltage is required to force the current through the transmitting wires, a condition which leaves less and less voltage available at the equipment for maintaining the current flow. This voltage drop or decrease along the line should not be more than twelve per cent of the bus-bar voltage of the power house for city systems and twenty-five per cent for interurban systems employing direct current. The trolley wire

from the power house or substation is usually reenforced in its carrying capacity by a feeder which taps into the trolley wire at frequent intervals. Since the resistance of the two circuits in parallel is much less than the trolley wire alone, it follows that the distance over which the transmission may be effected without exceeding the above percentage line drop may be greater. Figure 185 shows where a simple feeder is used in order to boost up the volt-

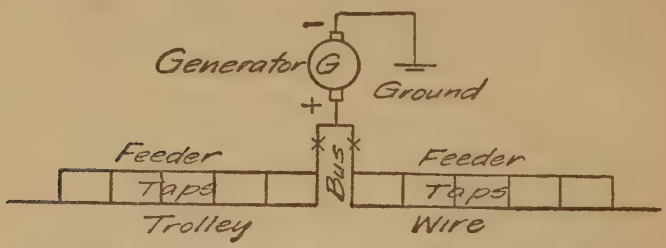


FIG. 185.—FEEDERS FROM POWER HOUSE TAP INTO TROLLEY WIRE TO KEEP UP THE VOLTAGE ON THE SYSTEM

age of the line at the most distant points. Where especially heavy traffic is operated over a car line, the so-called *multiple feeders* serve to maintain a fairly uniform voltage distribution at relatively long distances, as shown in Figure 186. It is of course as fully, if not even more, essential, to have continuity of service in the traction operation than it is in the regular process of industrial operation. Many plans have been tried in an effort to insure continuous service to car lines. Where the lines are interrelated, an accident to one part of the system will, of course, affect the remainder of it and may even paralyze the entire generating plant. Such connection of the lines should, if possible, be avoided and a flexibility of parts be permitted through some

forms of sectionalizing similar to that described for bus bars in the central plant layout as considered in the preceding volume. Figure 187 shows a scheme of breaking up the entire trolley wire continuity and of

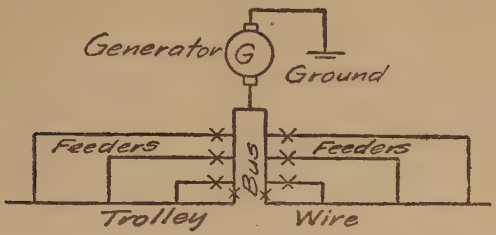


FIG. 186.—INDIVIDUAL FEEDER CIRCUITS FOR TROLLEY WIRE

forming sections each of which may be fed by one or more feeder circuits that radiate directly from the power house or substation. In case of a short circuit or grounded trolley wire on one section, the breakers in the power house will segregate this one faulty

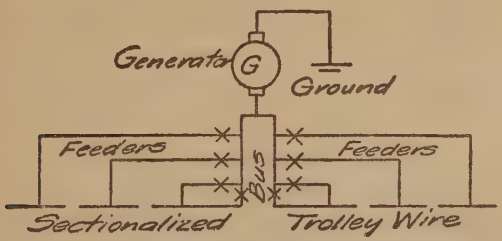


FIG. 187.—FEEDERS TO SECTIONALIZED TROLLEY SYSTEM

section and thus prevent any interruption to the service of the rest of the line.

It is a matter of economy in certain instances for a company to have a portable substation for supplying some rather isolated system or continuation of a sys-

tem, such as a summer resort or a recreation ground that is patronized only during certain months of the year. A box car resembling a freight car, containing the converting equipment and control apparatus of a substation may be run out into this section and installed on a siding with a connection to some high-tension line that runs in that vicinity or perhaps to a line especially constructed for that purpose.

For use on some of the rather long interurban systems, automatic substations are being devised and put into service. These are located every three or four miles apart and are supplied by very high

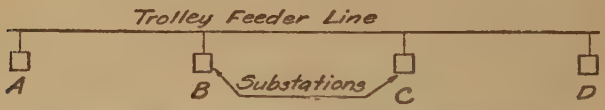


FIG. 188.—AUTOMATIC SUBSTATION INSTALLATION ON A TRACTION SYSTEM

potential alternating current. Figure 188 shows a simple diagram of such a layout. As an express or local car goes along the system, only those substations operate that are actually required to supply the energy. As soon as they are called upon for energy they automatically start up—self-synchronize and supply the direct current to the trolley line; but as the car passes on to the territory of other substations, those that were operating being no longer of service, automatically stop and take no more energy until another car comes along. Referring to the above Figure 188, the car is now between substations A and B, which are each supplying the most in proportion as the car is nearest to it. Now, as the car passes station B and runs along the system connecting B and C, the energy being supplied from B and

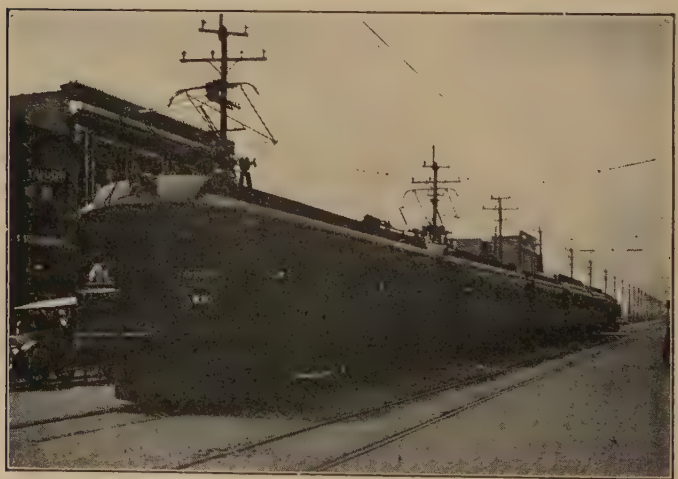
Photo, General Electric Co.

ELECTRIFIED TRAIN OF EIGHTY-TWO CARS IN SILVER BOW CANON

Photo, General Electric Co.

ELECTRIC GEARLESS PASSENGER LOCOMOTIVE ON THE CHICAGO, MILWAUKEE & ST. PAUL

TRACKLESS TROLLEY CAR



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ELECTRIC EXPRESS BETWEEN CHICAGO AND GARY

C, A is of no further service until another car comes along and it, therefore, shuts down. In this way the section of the line only between the operative substations is alive and a minimum of energy is radiated off as wasted heat. Furthermore, each substation consists of small and not particularly expensive equipment. One traveling operator may thus care for several of these substations.

One of the greatest steps ever taken in railroad engineering was the electrification of such railroad terminals as those in New York City, of various tunnels, as the Hoosac Tunnel and other sections of the railroads which were weak links of the existing system. The electric locomotives used in connection with this work are made in enormous sizes. Some of these used for freight service weigh approximately 300 tons. For both freight and passenger traffic, however, no type of transportation is as rapid and economical as such electrified systems. Only very recently, in Pennsylvania, a most unique test of one of these electric locomotives was conducted. This monster electric locomotive was lined up head-on with two of the finest high-speed powerful steam locomotives that make the record time from New York to Chicago. All the advantage was given to the steam locomotives, which were started and acted in unison to push back the electric leviathan of the iron rails. After some appreciable speed was acquired, the electric energy was slowly permitted to play through the electric locomotive and as this tug-of-war struggle continued and the throttles of both steam engines were opened wide, the electric locomotive slowly, but surely slowed down its opponents, stopped them, then inch by inch at first began to move them back until finally as full power was

turned on to the electric engine, it gained rapidly in speed. The hundreds of transportation engineers from all parts of the United States were given the surprise of their lives as they viewed this marvelous spectacle. On the Elkhorn section of the Norfolk and Western Railway, which reaches into the territory of the great coal fields, some twenty-two steam locomotives were there replaced by seven electric locomotives which not only did the work that these others had done, but also accomplished the work at considerably less operating expense, less maintenance charges, less breakage of the long trains by pulling out the drawbars, less wearing of the wheel shoes and brake shoes. Furthermore, in the winter time when the temperature is very low, the heat radiation from the fire box, boiler, and cylinders of the steam locomotive practically renders it inoperative and perhaps paralyzes the system. At this very time the motors of the electric engines are rendered most capable of overload and are most efficient in operation; because, as you will remember, it has been shown that the horsepower rating of a motor depends entirely upon keeping the heating of the windings and other insulated parts below a maximum safe value. Therefore, if the surrounding temperature is very low, the motor may operate greatly in excess of its normal rating without reaching the dangerous temperature.

The needed relief of the congestion of transportation in the mountainous sections of the northwest has been a great boon to the railroad systems of this country. It is no secret that the progress of transportation facilities in this country has fallen far to the rear of the rapidly marching increase of industrial enterprise. This situation has now grown most acute,

and in many cases the growth of the industries is being stunted since the products manufactured are of little value if they cannot be removed to the centers of demand and distribution. Neither can the manufacture of commodities proceed without the incoming supply of the raw materials. The railroads have in the past years failed to supply themselves with the increase of rolling stock and of trackage necessary to enlarge their sphere of activity. This has, in many cases, been due to the incapability of the administrative officers and in several cases to the interference by the Federal Government; but, whatever the causes, the results are startling and confront the business men of this country with a growing consternation. Temporary relief has been afforded by the service of large autotrucks; but the highways in this country are very poorly constructed to withstand the tremendous strains of the great loads that would in this way traverse them.

If the weak links in the great chain of transportation, however, can be strengthened by the operation of electrical haulage, some relief at least will be felt in the system. The mountainous sections of the Canadian Northern Railway, Chicago, Milwaukee and St. Paul Railway, and the Butte, Anaconda and Pacific Railway have been placed under electric operation with most gratifying results. Direct current has been used in each of these cases. The Chicago, Milwaukee and St. Paul Railway employs a 3,000 volt direct current system and the other two 2,400 volts.

POWERFUL ELECTRIC LOCOMOTIVES

The motors in these locomotives, which must be of huge size, are customarily placed on top of the truck structure and then connected to the wheels through

side-drive bars. These motors, of which there may be two or more, are as large as 2,000 horsepower.

By no means, however, is direct current the only electrical system employed. Single-phase alternating current and three-phase alternating current have been used. Only one system in this country uses the three-phase system, although in Europe it has met with great success and is quite generally employed. Three-phase induction motors are used for such operation. In this country, single-phase is most popular of the alternating current systems. Many successful lines employ it for their source of energy. The motors used in such propulsion may be either of the commutator type with the series characteristics or of the split-phase induction motor type. A standard line voltage for single-phase may be 11,000, which can be transformed down to the motor voltage by transformers located directly on the cars. The single-phase series type motors for large locomotives are used on the following systems: New York, New Haven and Hartford Railroad; Grand Trunk Railway; St. Clair Tunnel; Boston and Maine Railroad; Hoosac Tunnel; Spokane and Inland Empire Railroad; New York, Westchester and Boston Railway; and the Pennsylvania Railroad. The split-phase type of induction motors have been used on the Norfolk and Western Railway, where heavy mountain grades are encountered. Liquid starting resistances are used for starting these trains.

The use of single-phase has the following disadvantages: the motive power is relatively high in cost, and the efficiency of such a system is quite low. The advantages lie principally in the high efficiency of the substations and the relatively low cost of transmission and distribution.

The transmission system for all electric traction purposes may be either overhead wire, third rail, or the underground conduit system, as previously explained. In the overhead trolley wire system for street cars a grooved trolley wheel on the end of a pole is used and allowed to run along the wire. It serves to conduct the current from the line to the control apparatus, motors, and track. For the heavy traction, however, such as steam line electrification, overhead construction of the line has made use of a better device for serving the car with power. Instead of the trolley wheel, a so-called pantograph has been successfully used. The trolley wire is suspended from a single or double messenger wire so that it is horizontal. This permits of high-speed operation without danger of jumping the wire or of breaking it. Electric trains have been operated as high as 130 miles per hour in trial runs with the above equipment.

The subway systems and terminal systems of the electrified steam lines use the third rail for supply-

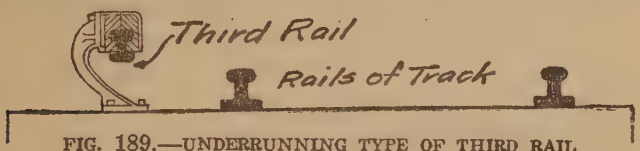


FIG. 189.—UNDERRUNNING TYPE OF THIRD RAIL

ing the energy to the motors of the cars. These rails may be of the unprotected, protected, or underrunning types. The underrunning type has some advantage over the first two types in regard to better protection against accidental contact, and against hindrance of the service due to snow and sleet accumulation. The contact surface being on the lower side, as seen in Figure 189, makes it self-

cleaning. In this type a heavy spring device keeps the shoe in contact with the rail. The Central California Traction Company operates its third rail of this type at 1,200 volts. Leakage from the third rail is extremely small and is usually negligible.

In the case of the subway train service, several of the cars of the train are equipped with motors and each motor car combines its power with that of the other in driving the train. Usually every other car has a motor equipment, which is so connected to a controlling system, to be found in the cab of the motorman of the front car, that all these motor cars are operated by the master controller there contained. These trains have powerful motor equipment which permit of very rapid acceleration and schedule speed.

When we actually stop to consider the many ways afforded us in the cities for traveling here and there, we must concede that they are all marvelous in their make-up. There are elevated systems, surface cars, subways, auto busses, ferryboats, and underwater tubes and tunnels. Every possible convenience is planned for the use and comfort of mankind in the travel that is necessary. In New York City and a few other cities, the five-cent fare still permits us to travel farther by electric traction than in any other way or in any other country. In these places one can travel considerably over twenty miles on a single fare.

The relative arrangements of generating units, transmission, substation equipment, and connection to the trolley system may be clearly seen by reference to the diagram as shown in Figure 190. Direct current motors can operate satisfactorily

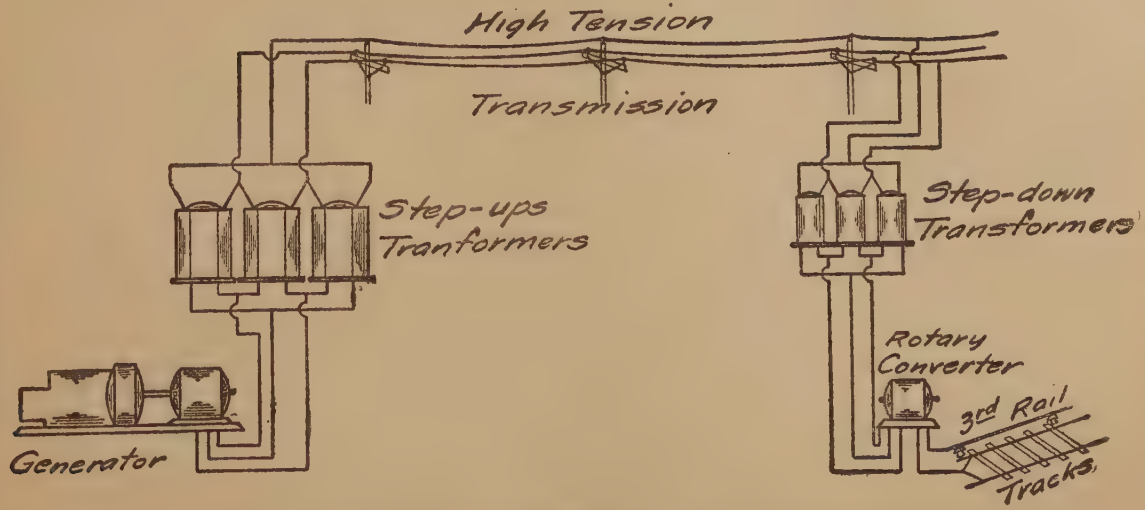


FIG. 190.—GENERATION, TRANSMISSION, CONVERSION, AND APPLICATION OF ELECTRICAL ENERGY

with the use of interpoles to as high a voltage as 1,200. For the 2,400 and 3,000 volts systems two motors are used in series across the high potential. There are some traction systems where a double trolley wire is used, one for cars traveling in one direction and the other for return cars, even where a single track is used with the necessary turnouts. Such use of copper is desirable, as it serves for additional feeder capacity and insures against the wear being entirely upon one wire.

The railway motors, of which there are a wide variety, are in practically every case four-pole motors, with a closed-in water-tight housing with handhole covers at the top to provide ready access to the commutator and brushes. There are two brush sets located at the top. Because of the lack of ventilation of these inclosed type motors they are rather larger than otherwise for the power rating.

The subject of regenerative braking of the electric locomotive-drawn trains is one of great interest in these days of improvement and efficiency. The electric motors of the locomotive that required energy from the transmission line on ascending the steep grades of the mountain sections were converted into generating units on the descent, and served to brake the speed of the train by converting the kinetic energy of the moving train into electrical energy which pumped back into the system to assist the main power-house supply and raise the efficiency of the entire system. Furthermore, a vast yearly saving in repairs and maintenance of brake and wheel shoes is thus effected.

CHAPTER IX

ATMOSPHERIC ELECTRICITY

AMONG the natural phenomena of the universe none create more respect and awe than the great strokes of lightning which at one single touch and in the most inconceivably small fraction of a second may level the most costly edifice, may crumble the most obdurate construction and may splinter the majestic oak which for centuries has stood as the emblem of strength and might. The power of the awe-inspiring geysers available for display in our National Parks, the mighty pent-up energy in the volcanic eruptions that shake the very foundations of the earth, and the power stored up in the high explosives made by the ingenuity of man—all seem mediocre in power and insignificant in their effects when weighed in the balance against the damage and disruption caused through the frequent visitations of the mighty force of lightning. Strange as it seems, it is nevertheless true that in general individuals do not fear the display of the electric flashes as they illuminate the heavens, like some great fiery serpent charged with vengeance that darts here and there with a speed so rapid that the eye finds it difficult to follow. Rather than fear this display, one admires it and stands fascinated only to be frightened and unnerved by the resulting peals of thunder, which, however, are as harmless as the babe in the cradle. If one is safe after he

has viewed the majestic sweep of lightning, he need have no fear of the thunder, because the capacity for destruction lies not in the noise of an explosion but rather in the energy of the expansive force of the explosion itself.

Many individuals, however, are of such a nervous disposition that they are painfully affected by the appearance of the lightning and also by the noise of the thunder as it detonates and rolls in its reflection from cloud to cloud. No effort on their own part can control these emotions of fear that run riot and play upon the motor action of the muscles of the body in many ways. Yet even the most self-controlled and the most masterful individual cannot at times refrain from a feeling of awe and an impression of his own helplessness and insignificance as he views the onslaught of the mighty arm as it cleaves the huge steel girders of a building with the ease that a child demolishes his block house or as it slays cattle in the meadow with the speed of a flitting thought.

The many wonders of nature and the remarkable freaks of the elements as they perform for our review, turn commonplace as we become familiar with their characteristics by frequent observation. The freaks of nature of the Yellowstone have no longer the novelty and the call upon the soul of man when they are once a part of the galleries of memory, nor are the glories of such superb scenery as the mighty cataracts of the Niagara or the towering mountain walls of the Banff or the huge cleft in the adamant foundations of the Sierras, which now gives us our Yosemite Valley, afterward so impressive as when first viewed. This experience is a natural one since the human mind constantly

craves the new, and when once the view has been experienced, it then becomes the old and establishes itself as a part of the past.

Such is not the case, however, with our experiences of lightning. We do see it and pass through the scenes of it probably much more often than we do the experiences of the above natural phenomena; and yet the impressions of it are always novel and we can recall, although years have passed, various characteristics that differentiate one display from the other. The general classification—*lightning as a natural phenomena*—is not new as it occurs in succeeding periods, but in regard to its behavior and characteristics in each display we can remark emphatically that there is never a repetition.

Probably many can recall electric displays like the following witnessed by one of the authors years ago, but the memory of which is still clear. Forked lightning from many directions in both individual and collective strokes played incessantly. Simultaneous action of many streaks of the lightning criscrossed each other and made the most grotesque figures in the inky blackness of the night. The roar of the angry heavens was incessant. One detonation vied with the next to shake the firmament and one could not help but fear that the very pillars of the world were crumbling and that the end of all had finally arrived. When the dawn broke with the glorious rays of the sun sweeping across the clear blue sky, one would stop to consider whether there had been some terrible nightmare or whether the present serenity could actually have been born from such a frightful rending and turmoil of a dark and stormy night.

Such natural disturbances possibly occurred long before the first man could realize and hear them. The heathen of ages past have worshiped them and have trembled in their presence, thinking that some angry god was pouring forth his wrath and vengeance because of displeasure and worldly activities. Later, scientists gained a further insight into and a clearer understanding of electrical phenomena. They experimented with the various manifestations of static electricity. They were able to produce minute replicas of the flashes of lightning. The ordinary discharges of static electricity occurred in common forked lightning. Then many began to wonder whether those great displays of nature were of electrical origin. Many years of speculation upon the probability of such an origin passed and still man approached no nearer to the facts of the case. Finally, an American scientist, whose name stands dear to the heart of every native of our great land, Benjamin Franklin, in 1749 settled the matter conclusively. He accomplished this by an experiment that showed that the atmosphere became charged with electricity as did the plates of a condenser, and that the efforts of nature to restore equilibrium resulted in the great discharges in the form of lightning between the clouds and the earth or from one cloud to another. This experiment was performed by leading the electricity from the sky to the earth by means of a kite. The current passed down the kite string to a key which was attached to the lower end from which sparks could be drawn in continuous streams.

A description, prepared by a contemporaneous experimenter, of Franklin's experiment forms an excellent picture of this great scientist with his son

going forth to convince the world of his convictions in regard to the energy of the atmosphere being electrical energy and identical with that used in the laboratory tests.

"Furnished with this apparatus, on the approach of a storm, he went out upon the Commons near Philadelphia, accompanied by his son, to whom alone he communicated his intentions, well knowing the ridicule which would have attended the report of such an attempt should it prove to be unsuccessful. Having raised the kite, he placed himself under a shed, that the ribbon by which it was held might be kept dry, as it would become a conductor of electricity when wetted by rain, and so fail to afford that protection for which it was provided. A cloud apparently charged with electricity soon passed directly over the kite. He observed the hempen cord; but no bristling of its fibers was apparent, such as was wont to take place when it was electrified. He presented his knuckle to the key, but not the smallest spark was perceptible. The agony of his expectation and suspense can be adequately felt only by those who have entered into the spirit of such experimental researches. After the lapse of some time, he saw that the fibers of the cord near the key bristled and stood on end. He presented his knuckle to the key and received a strong, bright spark. It was lightning. The discovery was complete and Franklin felt that he was immortal."

The expression of electrical discharge from the atmosphere is classified in three different types: one which most frequently occurs is called *forked lightning;* another type also common is known as *sheet lightning* or *heat lightning;* and the third type, only rarely exhibited is known as *globular* or *ball light-*

ning. To this latter type is accorded most fanciful and exaggerated behavior and only from reliable sources where some form of proof gives substantiation can the true characteristics be gleaned.

Even at present much speculation exists as to the complete reasons for the causes of lightning. There are many natural causes that may account for the electrification processes that underlie the lightning discharges. Unquestionably the phenomenon is to be attributed not to one cause alone, but to the aggregate of many fundamental causes. Of the result, however, and its associated cause, there is little doubt. Briefly stated, it is that electrical potential differences of great magnitude arise at times between the upper strata of the atmosphere and the earth, or between banks of clouds and the earth, or between adjacent banks of clouds. In any event, there is truly a condenser of gigantic magnitude formed, where the cloud banks or clouds and the earth constitute the respective plates of the condenser with the intervening air as the dielectric. As in any condenser, when the charge on the plates is increased, the potential rises and the strain of the electrostatic stress increases in the dielectric medium until a mechanical rupture actually punctures the insulation between the plates with the result that a current of electricity flows in an attempt to neutralize the charges and to restore a condition of electrical equilibrium.

Furthermore, it is quite substantially agreed that for the linear length of rupture that frequently occurs, the potential difference must have a magnitude of many millions of volts. Measurements have been made in order to ascertain the approximate values of such electrical potential differences and

values ranging from about twenty to fifty volts per foot of altitude have been found.

Regardless of how the electrification does take place, it is a fact that static electricity resides only on the surface of a body. The same is true of the tiny patches of vapor in the atmosphere. These acquire charges of electricity, which lie wholly on the surface. As the potential of the body depends upon the charge per unit of area or the density, consider the formation of eight little particles of charged vapor merged into one minute drop. The diameter of the drop is only twice that of one of the vapor particles, the charge eight times as great, the area is only four times larger and, consequently, in reference to some original comparison point the potential has doubled. By a combination of these minute drops into a larger drop the potential difference still further accumulates until a magnitude of enormous proportions may result.

During clear weather electrification of the atmosphere is proceeding continually, and in this case the atmosphere is invariably positively charged in respect to the earth which is negatively electrified. During stormy or threatening weather, however, when cloud formation predominates, the polarity of the cloud potential with respect to the earth and to each other changes in rapid successions sometimes many times during the brief spell of one-half hour.

The discharge of a system of clouds by the passage of an equalizing flow of current does not take place as a current of electricity flows through a machine when the switch is thrown in as for a motor or incandescent light. The discharge is distinctly one of a condenser nature, in which the discharge

takes place from one plate to the other, then reverses in its flow, being now from the latter to the former, and so on, until the energy of the charge is dissipated in the form of friction. Instead, therefore, of the charge being of continuous flow in one direction until the discharge is completed, the flow oscillates between the plates many hundreds of times, as is the case of a charged condenser when a wire short-circuits its terminals, as explained at the

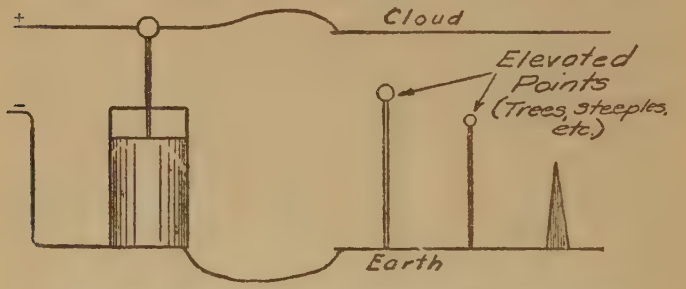


FIG. 191.—SIMILARITY OF LIGHTNING TO CONDENSER ACTION

conclusion of "Static Electricity" in the preceding volume. Such a condition is represented in Figure 191. As there explained, it is analogous to a deflected spring when suddenly released. It oscillates about its final position of rest at a rapid rate until the energy of the pent-up position of the spring has been all used up on heating the air and in overcoming the restraint of itself toward bending.

This lightning flash is not extinguished at the end of its discharge, as one would expect it to be, but it reproduces itself in the reverse direction, for the same reason that a carbon arc continues on an alternating current when once started. As the arc is struck and the electrodes pulled apart, the heat of

the electrical discharge or current flow vaporizes and ionizes the particles in the path and renders them readily conductive in the path, so that as the voltage falls to zero and then increases in the reverse direction, the current immediately begins to flow in the reverse direction because the resistance of the path has been reduced to almost nothing by the previous heating.

It was explained under "Static Electricity" that a charged body having various fine needle points would readily discharge itself by electrifying the air particles because of the high density of electricity about the points and edges, and that the convection currents thereby set up would dissipate the energy of the charge on the body. The Hamilton Mill is an example of how the reaction of this discharging process produces rotation as does the reaction type lawn sprinklers. The reverse process is also true, that if the atmosphere is charged with electricity, by introducing a rod or other body having sharp points, the charge may be transferred to the rod and conducted to the ground. Such is the action of lightning rods, which will be considered more in detail at a later period.

It is quite commonly believed that a lightning discharge takes place between a system of points in the oppositely charged bodies of clouds, or clouds and earth, and discharges the energy residing only in that very locality. Such belief is, however, quite erroneous, since a discharge may affect hundreds of acres. It is true that the clouds and the earth are relatively poor conductors when compared with the metals that form the plates of an artificial condenser. It is, indeed, a fortunate condition that the clouds and the earth are not perfect conductors,

since, in this event, a discharge between these two huge systems as plates of a condenser would result in the instantaneous discharge of the entire earth, and the disruption that would result might create damage to vast territories and the noise and concussion would injure the delicate membranes of the ears of human beings and animals for great distances. The fact, however, that these bodies are only partial conductors, results in rather large areas being drained in the energy of discharge.

The distance at which a lightning stroke takes place is vague in the imagination of most people. They find it hard to tell whether they think it to be one-half mile or ten miles distant. Yet, with the aid of a few facts of fundamental physics, it is a very simple matter to estimate the distance at which the stroke occurred. One sees the discharge almost instantly, and yet the report of the discharge, or the thunder in other words, may follow after many seconds have elapsed. Sound travels in clear atmosphere at the rate of about 1,115 feet per second. Count the seconds that transpire between the lightning flash and the clap of thunder. Multiply this time by the distance sound travels per second and you will have the approximate distance in feet to the locality of the stroke.

Many people have inquired about the nature of thunder and about its relation to lightning. Their knowledge of thunder is limited to the experience that it accompanies lightning and that it frightens people. The real facts that scientifically account for thunder phenomena are relatively simple and similarly may explain many other effects that occur daily in and about the home. The electric light bulb drops and its breaking is accompanied by

thunder, or, as we more usually state it, by a sharp report. A revolver is shot off and the report follows the flash from the barrel. That is thunder. The farmer on the hillside touches a match to the fuse that leads to the charge of dynamite securely packed in the drilled hole in the solid rock. The blast of flying rock as we view it from a safe retreat is followed by a powerful detonation, which is identical in nature with that of thunder. In each such case enumerated, the sharp report is occasioned by the air from all sides rushing in to fill a void called a *vacuum*. In the case of the electric lamp bulb, the vacuum had been established by previous treatment, but, for explosions, the enormous heat of the instantaneous expansion of the exploding medium causes a large volume of partial vacuum and the air as it rushes into this space to replace that which was previously evacuated, causes by its impact the report that comes to our ears. In the case of lightning, there is a flash that may be miles in length as it discharges from cloud to cloud. This flash or arc, which is accompanied by a great evolution of heat, causes the air to expand and attenuate, thereby creating the partial vacuum throughout a very great amount of space. The air as it rushes together from all sides to fill this gap, causes the deafening detonation that could not be equaled by hundreds of tons of the highest explosives known to man. This report is known to us as *thunder*.

The general features of forked lightning have been given in the preceding pages. The discussion has been confined entirely to the effects rather than to the causes. The effects are well known since observation only is required to fix the laws of its general activity. The cause, however, frequently even

for the most simple phenomenon, is concealed behind the opaque curtains of nature and only after the scientist has removed this curtain can the real causes be revealed.

One process that goes on indefinitely and which will continue so is the evaporation from the great oceans of the earth and other vast bodies of the continents. It has been conclusively proved in the laboratory that evaporation is accompanied by electrification and that the atmosphere in this case becomes invariably positively charged to the water surface or earth negatively. This reasoning is in accord with the conditions as found in nature, namely, that in clear weather where the electrification by the ever-present process of evaporation goes on, the atmosphere is always found to be positively electrified and the earth negatively charged. This form of electrification by means of evaporation is true only when the water contains salts of metals. Of course, the ocean water is rich in ordinary salt or sodium chloride and the evaporation constantly in progress over these great bodies produces a vast store of electrical energy. Even the waters of lakes and rivers have sufficient minerals dissolved in them to cause electrification as they are evaporated.

Sir Oliver Lodge, the renowned English scientist, who has devoted much time to the study of atmospheric electricity, has stated a cause for some of the electrification that seems to accumulate in such vast quantities in the system of the traveling storms. As the storms, of the nature of cyclones, hurricanes, tornadoes, and all severe atmospheric disturbances, sweep about, they are known to have a rotary or whirling motion. If the axis of such a whirling mass be in such a position that the rapidly

moving air brushes over the surface of the earth, a condition is established very similar to that of the friction machine where a cylindrical rubber makes contact with a stationary member. The revolving mass of air, as it becomes electrified by friction with the earth, gives up its charge to the upper air strata and thereby forms a condenser of which the earth and upper strata form the plates and the intermediate atmosphere the dielectric. The upper strata may be twenty miles or more above the sea level, a distance too great for the discharges ordinarily to take place. At certain intervals, however, the cloud formations are such that the charge is brought down sufficiently near the earth to cause the disruption of the atmosphere.

The second type of lightning which is called *heat lightning* or *sheet lightning*, is most often seen in the summer time. It is really the reflection of a far-distant lightning display against banks of clouds at our horizon. Usually these storms are so far remote that the noise of the thunder does not reach us. Usually there is no rain or rainstorm that accompanies this form of lightning.

The third type of lightning is called the *globular* or *ball lightning*. It is indeed true that its antics are most remarkable and its features are as variable as the winds that blow. Probably for that very reason, the mythical proceedings attributed to the occurrence of ball lightning would make the ordinary proverbial fish story fade away in comparison. This type of lightning discharge is quite rare and its maneuvers are a mystery to the most scientific.

There is one case on record where a large ball of fire came down the chimney of a house, entered a room and rolled slowly across the floor and dis-

appeared through a crack in the wall and not a person of several who were sitting in the room and saw the proceeding was harmed.

Another appearance of globular lightning was recorded as follows: "At 4 p. m., a great deal of wind, lightning and heavy black clouds passing overhead; at half-past six a ball of fire struck the mainmast, passed through the upper deck, making a hole about eighteen inches in diameter and four feet from the mast, when it exploded on the gun deck with a tremendous noise, and forcing the deck upward abaft the mainmast. About a quarter past seven another ball of fire struck the mainmast and ascending upward and passing through the center of the mast, it exploded with a loud crackling noise like the roll of musketry, with vivid sparks, breaking several large iron hoops which surrounded the mast, and scattering the fittings in all directions. A sailor, on approaching the hole on the deck, was scorched so severely that he died twelve days after in extreme agony. The compass was not affected nor was there any swell."

Dr. Houston states the belief that accounts most probably for the peculiar formation, behavior, characteristics and disappearance of this globular lightning: "The highly important facts that have been recently discovered concerning the possibility of electric discharges tearing off minute fragments from the atoms of ordinary matter, and forming therewith an extremely tenuous kind of matter, possessing properties peculiar to itself, render it not at all improbable that the long-sought-for explanation as to the cause of globular or ball lightning may be found in the formation, under the powerful action of lightning flashes or discharges, of small quanti-

ties of intensely heated and highly charged matter, formed from dissociated atoms. Such matter would possess the exceedingly light and highly rarefied condition that Plante pointed out as necessary for the nucleus of the central portion of globular or ball lightning. Moreover, the great stability that the atoms of ordinary matter possess, a stability so great that it has only been recently that their disassociation or tearing apart has been believed possible, would appear to indicate a corresponding degree of intensity with which such matter tends to recombine and again enter into its more stable form as ordinary matter. Both the levity of the globes of fire, as indicated by the ease with which they float about in the air, and the intense force with which they generally explode, as manifested by the destructive effects they produce around them, and the loud reports attending their breaking up, would seem to render this explanation quite possible, the explosion being probably due to the energetic recombination of the disassociated atomic matter, as soon as it loses its high temperature or other condition which prevents the fragmental atomic matter from recombining."

The query as to why immediate precipitation of large drops of rain always accompany a heavy peal of thunder has been many times asked and perhaps as many times incorrectly answered. Many have thought that the vibrations and jar of the great detonation of the atmosphere have caused a combination of many drops into huge drops. The real reason for this coalescence of the smaller into the larger drops have not a mechanical origin of the above type, but rather an electrical one. This process of precipitation of the large drops and their

formation from many small ones has been for centuries past a secret concealed in the heart of nature. Only within a decade has its usefulness been adapted to the needs of man. It has been proved by fascinating experiments that a vessel containing a heavy atmosphere of dust, smoke and gases can be so affected by the presence of an electrified environment that the minute particles therein contained become greatly agitated, collect into large drops or balls and either fall to the bottom of the jar or else fly to the side of the vessel and cling there. The entire atmosphere is almost instantly cleared of the solid matter held in suspension. This principle of precipitation of solid particles from gases and from the atmosphere by means of electrification was soon put to practical use by such men of genius as Prof. A. F. Nesbit and Dr. Cottrell. The precipitation of solid matters in flue gases, which cause such annoyance and uncleanliness in congested sections of business and manufacture, has now become a means for cleaning these gases and vapors that previously poured forth over the community. Not only has this become a means for cleaning the gas and improving the health of the neighborhood, but also the recovery of the precipitate has become a means of income from by-products thereby made available, which in many instances has repaid the cost of installation within one year and thereafter realized more profit than from the primary product of manufacture.

The condition affecting the coalescence of the rain particles into huge drops is not a mechanical one, therefore, but rather the result of an electrification process in precipitating the solid matter as in the above-mentioned experiment. The accumulation of

electricity in the clouds and in the earth causes a powerful electrostatic field to act in the atmospheric regions in attempting to clear the atmosphere.

There seem to be two rather well-defined classifications of thunderstorms: first, hot afternoon storms; and second, the great storms that sweep across the country in certain ill-defined paths.

The hot afternoon storms are of local origin and in general confine their activity to local areas. Such storms are usually heralded by the appearance of clouds in the west of a billowy nature, which soon appear dark and lurid. Such dark masses of clouds are an indication of a heavily charged condition. The air is oppressive before the storm, and then becomes cool and even refreshing as the storm is about to break. Such a formation often bears the name of *thunderhead.*

The actual cause of the thunderstorm lies in the physical fact that as the heated air of a locality rises and creates a depression of the atmospheric pressure, from all directions a movement of other layers of heated, moist air, to this locality to neutralize the pressure difference takes place. This air, as it, too, rises, becomes chilled by contact with the above strata of cooler air and forms condensation of this vapor into rain drops. The evolution of the heat here released by the condensation process causes the layers of air still higher up to be warmed. The inrush of the moist air from all directions at the surface of the earth, carrying with it, as it does, charges of electricity, increases the electrification of the clouds and raises the potential difference. As the coalescence of the vapor particles takes place, the potential difference is rapidly multiplied until finally a discharge takes place from

the clouds as a *flash of lightning*. *Cloudbursts*, which are rather frequent in very hot, arid sections of the West and Southwest, are really exaggerated forms of these thunderstorms. They operate over a very limited section and continue for only a very short period of time. But many times the excessive rainfall causes considerable damage to crops and the dry channels of streams are converted into raging torrents.

The great storms that travel across the United States from west to east can be predicted quite closely by the United States Weather Bureau. This institution has made a study for years of the paths taken by these storms, their deviations, velocity, intensity, and other characteristics, and are, therefore, equipped to predict as soon as a storm approaches the western coast what the possible subsequent action will be. The center of the storm is marked by the area of lowest barometric pressure. Maps are made by this department daily showing the directions of storms as they sweep over the country. The speed of such storms as they traverse the country ranges between twenty-five and sixty miles per hour. The appearance of thunderstorms is by all means most frequent east of the Rocky Mountains. On the Pacific Coast such storms are most rare. The topographical layout of the country is one factor in determining the formation of thunderstorms.

The protection of homes against the destructive stroke of the lightning dates back to about the time of Franklin, who recommended that wires be run up to the highest part of the structure from the ground and terminate in mid-air with several sharp points, since these would cause a gradual discharge

of the charged atmosphere and clouds. The lower end of such protective rods must be thoroughly embedded in wet earth. A load of charcoal buried a few feet deep creates an ever-damp location for the ground plate to be attached to the wire. The tendency for destructive work is far less in the cities than in the country. This may at first not seem plausible; but when one remembers that the tall skyscrapers which are constructed of steel girders, reach far up into the heavens, it will be clear that they act as very effective protectors. The lightning rod should be as free from any angles as possible. Further, experience dictates that an iron rod is more effective than any other material. Again, the stranded or ribbon wire conducts more readily than does the solid rod. There are certain types of lightning strokes that are not readily influenced by the conductive medium of the protective rod; but, in general, the rod is a most effective safeguard. The person who argues against its use by saying that it is not a protection carries about the same weight of conviction as the man who will not trust his money in the repository of a savings bank and hides it in his mattress because he is afraid the bank will fail.

CHAPTER X

ELECTRICITY ON THE FARM

THE American farmer of to-day is conspicuous among those of our great land who take kindly to the progressive spirit of the times. He is eager to adopt any measures that suggest to him improved methods for the cultivation of the farm and for the transportation of his products. In the past no class of producers has suffered injustice nor been deprived of his rightful earnings by the unscrupulous middlemen and market manipulators to the same extent that has the general class of farmers. Their labors have been from sunrise to sunset, and the result of their efforts have kept the wheels of the national machine oiled and working smoothly. The hungry mouths of the congested city have found relief in the farmer's toil. And yet the average farmer has not come into his own, at least as far as the world's wealth is concerned. The fabulous prices for garden commodities in the city market places lead us to think that the farmer fares well, but the ravaging profiteers of the city prey upon the helplessness of the producer in marketing his goods and seize the larger share of the gain. The spirit of the times, however, is undergoing a beneficial change and the farmer is beginning to emerge with even more than the respect to which he is entitled.

How appalling is the utter dependence and helplessness of the inhabitants of our large cities and environments! It requires but a tie-up of transportation facilities for a few days and the perilous position of the food problem causes us to feel our dependence. When the economic law of supply and demand operates without the manipulation of the trade pirates, who buy at their own low bid from the farmers and sell only at the highest prices, the amount and quality of production will have its direct effect upon the market in affecting the price. If the farm produces the so-called bumper crops, not only should the farmer be rewarded for his thrift and skill and realize financial gain, but also should the consumer feel the period of plenty by the barometer of low cost. The point, therefore, at hand is that any influences that tend to stimulate production of the farm resources have a beneficial effect upon the universal class of people called the *consumers*.

The youth of to-day differs from the youth of yesterday in many ways. The opportunities for higher education are not only to-day rapping at the door of every young man, but are being welcomed as never before. The youth sees in perspective the possibilities of becoming a great figure in finance, industry, and commerce. The call of the farm with its hard work, lack of entertaining environment and relative isolation do not appeal to him. The migration of the country boys to the city has caused concern among the farming classes. The demand for farm help has so far exceeded the supply, that wages for these men have soared to values that heretofore would have been considered fabulous.

But, it is, according to the old adage, an ill wind that blows no good, and so in this case a redeeming feature has operated in favor of the farmer. The lack of farm help, the high cost of this labor and the independence of such labor as is available have all conspired against the operators of farm production. In this dark hour of need behold on the horizon looms the light of solution for these tribulations. Let electricity replace the hands that before were necessary. Can you imagine seven cows milked, the milk transformed into the various products and the skimmed milk already placed in the feeding tanks for the pigs all accomplished within the brief space of seven minutes? Such is on record with the use of electrical methods. At no time could the electrical way gain the momentum of its extensive application as in these days of turmoil of labor. Think of it—electric power can be applied economically to more than one hundred farm and household purposes!

The transmission and distribution lines, the power plants and electric railways have spun a fine fabrication over nearly every part of our great land. The great power with its conveniences has approached the gateway of many farms lying far distant from the centers of distribution. By bringing this great force under the control of the farmer one man can do work that several men previously did and, further, this accomplishment may be realized in far less time. In considering the economics of the utility of electric power, we should first regard the actual work that may be accomplished through the employment of electrical devices. Then, secondly, how does the cost of this service compare with that of other methods of performing the same

work. Gas engines and steam engines have been employed for certain types of farm work for years past, where work was done on a large scale. But the electric motor has a flexibility of application, ease of movement here and there, lightness and compactness and relative fewness of moving parts and simplicity of operation, all of which recommend it more fluently than could any words of a salesman. The motor has only a couple of bearings that require a little oil once in six months. It is not affected by extremes of weather conditions, has no adjustments to cause trouble or render it inoperative and the difficulties of fuel are entirely eliminated.

Electric motors may be fastened on the ceilings or walls where they are out of the way. Or if placed on the floor will occupy only one-eighth of the space that a gasoline engine of the same horsepower would have. Its weight, also, would be only one-quarter of that of the gasoline engine. Furthermore, it can be controlled at a distance, has a minimum of fire hazard since there is no danger from boilers, pipes, flues, and gasoline. Electric motors are more easily installed and cost less to operate than gasoline engines.

Of course, the conditions on one farm generally differ from those on any other, and in each case the specific requirements must dictate to what extent motors should be used, as well as their size and the type. Sometimes one motor may be used to drive several devices by means of belt drives. Such a group installation of machinery for one motor may reduce the first cost of motor purchase.

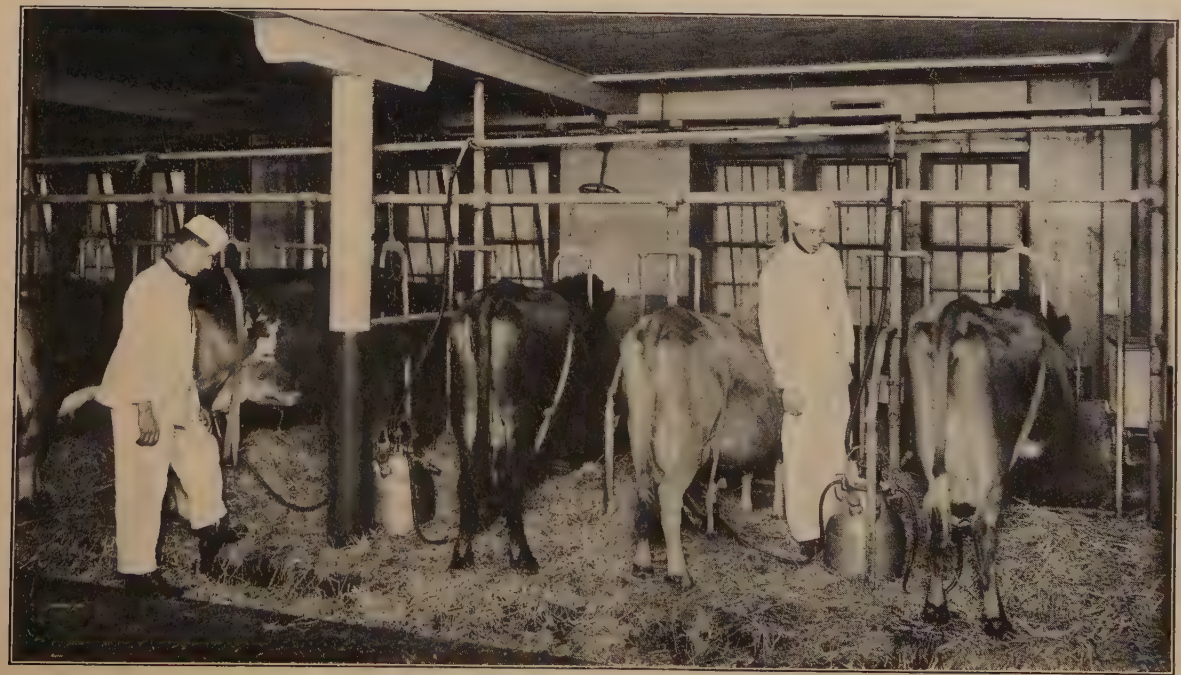
The following general data and the information contained in this chapter have been taken from

various bulletins of prominent electric manufacturing companies which have made extensive studies in this field of activity. Usually, in the outlying districts only alternating current will be available. In such cases the "squirrel cage" induction motor is most desirable because there are no brushes to produce any sparking. The fire hazard is thereby reduced to the lowest possible. The simplicity of its design and operation, further, requires practically no attention. If, however, direct-current motors are to be used in places where there is dust and inflammable material, the motor should be wholly inclosed to preclude danger of fire.

The use of electricity on the farm is not a proposition of luxury and convenience for only the "well-to-do," but its use is a business proposition founded upon a dollars and cents basis. To bring these facts of economy down to a basis comparable by actual figures with the cost of horse and man service, the following quotation from a bulletin issued by the General Electric Company will serve to show clearly where the motor ranks in regard to cost.

"To arrive at a correct comparison of the cost of different operations requiring power it is necessary to weigh against the actual expense of electricity such important advantages as emancipation from the 'help' problem, increase in quantity, and betterment in quality of the farm product, with all the indirect if no less tangible benefits in greater convenience, comfort, and safety which invariably follow the adoption of electric power.

"As an interesting fact from the viewpoint of economy, statistics have shown that the average horse of the farm works on an average of three hours a day during the 313 working days of the



MILKING MACHINES OPERATED BY ELECTRICITY

Photo, General Electric Co.

International Newsreel Photo

MOTORIZED EQUIPMENT FOR GENERATING ELECTRICITY AND MAKING MOVING PICTURE SUNLIGHT

year. On this basis, and taking into consideration original cost, interest, depreciation, and maintenance charges, the work accomplished by the horse actually costs between eight and nine cents an hour. The average cost of normal farm labor is eleven cents per hour. As a man, in the same time, can do from one-sixth to one-eighth of the work done by a horse it seems logical to estimate that manual labor costs about sixty to ninety cents per horse hour.

"In marked contrast to the cost as figured on the foregoing basis, electric power can be purchased from a central station or generated on the farm at a price varying between one and twelve cents per horsepower hour, depending on local conditions, size of the plant, and the amount of current consumed.

"In making cost comparisons it must be borne in mind that the electric motor can operate twenty-four hours a day, whereas a horse can be used on an average of only three to six hours out of the twenty-four. The average life of well-built electrical apparatus is considerably longer than that of the average horse. The electric current when not running the motor can be used for lighting, cooking, ironing, heating, or a number of other purposes, whereas a horse, when not working, is serving no useful purpose. Motors, lamps, and other electrical appliances "eat" only when they work; the hired man and the horse must eat even though they do not work, and must eat and rest for long intervals between the periods of productive labor.

"The first cost of a one-horsepower motor is between $50.00 and $75.00; that of a horse from $150.00 to $250.00; the average operating cost of the motor will be about six cents per horsepower

hour, animal labor about eight cents. Manual labor will cost about ten times as much as either horse or motor.

"The following table indicates the amount of power required to run various forms of apparatus on the farm:

	Approximate Horsepower Required	
	Min.	Max.
Cream separator	1/8 to	2
Milking machine	1/2 "	5 1/2
Butter churn	1/8 "	3
Bottle washer	1/6 "	1
Water pump	1/4 "	100
Washing machine	1/8 "	2
Vacuum cleaner	1/8 "	5
Grindstone	1/4 "	1
Horse groomer	1 "	2
Wood saw	2 "	10
Corn sheller	1/2 "	15
Shredder	10 "	20
Ensilage cutter	10 "	25
Feed grinder (small)	3 "	10
Feed grinder (large)	10 "	30
Threshing	10 "	70
Hay baler	3 "	10
Refrigerator	1/2 "	25

"The exact purposes to which electricity may be used in farm labor may be considered under the heads of dairy work, barn labor, refrigerating and cold storage, workshop, field labor, transportation, irrigation, miscellaneous uses in the house and lighting."

ELECTRICITY IN THE DAIRY

One of the cumbersome and tedious tasks of the dairy is that of milking the cows. The application of ingenuity on the part of engineers has developed a method of performing this task by electrical

methods that has completely revolutionized the former dairy methods. Electric power has been adapted to dairy machinery originally designed for hand operation as well as to that of self-contained design of recent manufacture. Vacuum pumps are driven by means of a small electric motor. The milking machines are attached to the cows and connected with the vacuum pumping system. Such pumps may even be connected to a pipe system so that the milk may be conveyed to the aerators or directly to automatic bottling machines or run through cream separators and churned into butter, whence the buttermilk or skimmed milk may be distributed to the calves and hogs through one complete pipe system. Such a complete method of dairy operation means a minimum of labor. Furthermore, such conveniences foster and stimulate the growth of a profitable business into an industry of large scale operations.

The following machines of the dairy may be driven by electrical means: cream separators, milking machines, milk cooling circulating pumps, churns, refrigerators, bottle washers, cream testers, milk clarifiers, cream ripeners, milk mixers, butter tampers, milk shakers, curd and casein grinders.

ELECTRICITY IN THE BARN

Cleanliness about the barn and stables in these days of enlightenment about malignant germs and bacteria is being given consideration and being practiced more and more. Legislation in some States has established for the protection of the public the periodic inspection of premises where products are sold into general use. The pumping system above referred to for use with the milking

machines may be operated in conjunction with vacuum cleaning operation not only for currying the horses and cows, but also for general cleaning purposes about the barn. It is most sanitary, since instead of stirring up the dust and causing it to settle in undesirable places, where it might contaminate the farm products, it is drawn into the vacuum tube and thus prevented from doing any harm.

A motor-driven churn will produce from ten to twelve pounds of butter in fifteen minutes at an expenditure for energy of not more than one and one-half cents.

Many of the barn chores may be facilitated by the use of electrical devices. Water may be pumped and made available wherever required. Hay may be unloaded, packed in the loft or carried to the horses by electrical devices. Litter and waste products may be conveyed to storage departments. The silo may be filled with ensilage cut by electric power. It is not at all necessary that each machine should have its motor attached and applicable only to that one operation; but rather the one motor called possibly a *handy motor* or *general utility motor* may be made readily portable so that it may be quickly set up and operated for any of the required services. The following machines which are to be found on farms for lightening the labors may be operated by the use of electric drive: Water pumps, feed grinders, corn shellers, fanning mills, grain elevators, corn crackers, oat crushers, alfalfa mills, horse groomers (vacuum type and revolving brush type), horse clippers, sheep shearers, hay cutters, grain graders, root cutters, bone grinders, hay hoists, cider presses, electric brooders, electric incubators, clover cutters and grindstones.

ELECTRICITY IN THE WORKSHOP

An up-to-date farmer of to-day cannot afford either to lose time in having many of the minor repairs made in town at the village smithy nor is he willing to pay the expense incurred by these jobs, when a relatively small outlay of capital will equip him with a forge, forge blower, small lathe, drill press, emery wheel, wood saw, and other essentials. In fact, a handy man who can do repair work when necessary is often sought by farmers who operate on a large scale. The little shop may be inexpensively equipped with the necessary shafting and pulleys and belts so that the machines may be connected up for operation as desired by throwing over a lever rod. Tool sharpening is an activity that every farmer must undertake both in winter and in summer. In summer scythes and mowing machine blades, while in winter the axes, hatchets and brush scythes, must be kept with keen edges. One man, as a rule, can do the necessary sharpening where the electric motor does the turning, whereas by the old method it was always a two-man job. The wood saw which will cut many cords per day into sixteen-inch lengths or to any desired length is an asset of inestimable value to the man who handles cordwood.

ELECTRICAL REFRIGERATION AND COLD STORAGE

The progressive farmer of to-day realizes the immense advantage gained by the use of ample cold-storage room. The holding over of products in his own warehouses for advancement in market prices means dollars in his pockets rather than the loss that goes with selling on a glutted market. Such reservoir absorption of surplus by the farmer can

only be a possible and feasible process where he can employ electrically operated cold-storage plants. The use of ice in the old-fashioned type is extremely unsanitary and wasteful and there is always an uncertainty of supply. Furthermore, the atmosphere is always saturated with moisture where ice refrigeration is concerned and a condition established which promotes spoilage and waste of products. The electrically operated cold-storage plant, on the other hand, permits easy and close regulation of temperature, has the advantages of a dry atmosphere, greater space for storage, absolute cleanliness, a minimum of labor for attendance, and automatic control by electric thermostatic regulation. Such an investment may very soon pay for itself from the excess profits made possible by the judicious harboring of delicate farm products.

ELECTRICITY IN THE FIELDS

The application of electric drive for machinery in this line of farm activity still requires much investigation and experiment. Certain types of machines have yielded readily to the electric drive and have become an economic necessity, while in other cases the type of work seems to be little adapted for the application of electricity. Electric motor drive has been used successfully for operating ensilage cutters, cordwood saws, huskers and shredders, concrete mixers, grain threshers, hay balers, clover hullers, rice threshers, pea and bean hullers, air compressors for spraying machines, and wood splitters.

The construction of good roads has given the farmer a marked advantage in the rapid transportation of the products of his labor. Electric trucks

and automobile trucks are serving an economical addition to farm equipment. There are times of the year that the slow-moving loads with horse haulage cause impatience and emphasize the need of the quick action of the electric trucks. Further, the danger of loss and the resulting worry that would accompany a glorious harvest which may be ruined through inadequate labor and inefficient transportation need not be feared if the quick and economical method of truck handling is employed.

Many other uses of electricity on the farm should be noticed. The gardening is made independent of droughts by installing irrigation and sprinkler methods. The crops are practically insured against failure in this way. On a farm, a pumping station of good size and power is a most valuable asset for self-protection against the ravages of fire. Statistics show that of the many millions of dollars of fire loss that occurs annually in the United States over fifty per cent of the damage occurs in rural districts. The majority of such fires are due to the use of dangerous illuminants.

This introduces the subject of artificial lighting for farm use. No other method combines the safety, cleanliness, and convenience that the electric lighting possesses. It is especially adaptable to places where inflammable materials are kept. No matches are required and there is no soot, smoke, dangers of explosion, need of cleaning, or disagreeable work of filling and trimming as involved in the use of kerosene and other types of light.

HOME GENERATING PLANTS

In some localities, however, the network of electric wires has not yet made available to the

progressive farmer the uses of electricity and he has been limited, therefore, and handicapped in his endeavor. Farmers of this spirit of up-to-date methods have not been daunted in their desires for electric power. There lie open to these pioneers—and every community has at least one—two ways of obtaining the power that he desires. The first is to build a suitable plant for his needs where he may employ a gasoline engine for the prime moving element. There are self-contained systems of this type put out by Sears Roebuck and Company, one by the Dayton Electric Laboratories Company (Delco), one by the General Electric Company, and many others less known designed to meet the needs of illumination and small motor operation in the home or on the farm. These sets are usually low voltage units and serve a need in lighting, but for power purposes for farm utility they would be insufficient. A plant unless it serves the purpose for which it is designed is of little value, and to the unsuspecting victim of the sale it becomes a means of annoyance and an instrument of self-reproach for his expenditure of money. Consequently, the purchase of a set should be made from a large, well-established and reliable company who will advise with the purchaser and thereby protect his interests.

First of all the farmer must consider carefully the devices that he would need to facilitate his work electrically instead of as he is at present conducting it. Then the far-sighted man will look a few years into the future and let his imagination play a little, guided and constrained in its ramble by the prospects of success, so that the extent of future additional equipment may be estimated. From the

amount of power required by all of these devices either the farmer or his technical adviser may compute the size of the generating unit that he should consider and whether it will be direct or alternating current. Then a good reliable make of gasoline engine should be chosen to operate the generator. Such a plant should be contained in a closed-in room of the barn, perhaps in the basement—so that the noise and jar could be reduced to a minimum. Furthermore, an arrangement of storage batteries is very desirable so that the illumination energy may be derived therefrom rather than from the larger machines operating. The storage batteries need be charged only as required and yet, when the power is demanded for motor operation, the large set may be run. During any period of operation the storage batteries, of course, may be charged for use as required.

Another possibility for the farmer who is favorably located is that of developing a hydraulic system from a large-size brook which has a steady flow in summer as in winter, or from a small river. The man who has initiative and a small amount of capital may reap a good return on his investment even by operating a fairly large plant and selling some of his energy to the neighbors. Such a plant may be constructed by having a dam built across the small stream in order to create a head of water so that the energy of its fall may be employed to drive the hydraulic turbines or water wheels as a prime moving element to operate the generator. Sometimes a spring high up on a hillside can be piped down to the foot and a small Pelton water wheel used. There are thousands of horsepower of small plant possibilities that are annually going to

waste at the very door of the farmer, who yet cannot look sufficiently far ahead and lacks the fire of enthusiasm and the push to utilize it. If the development should be made at a considerable distance from the house or barn, as would probably be the case of a hydraulic plant, then the use of an alternating current plant would be the suitable system so that the energy could be transmitted at a higher potential and save a relatively large outlay of capital in the copper or else sacrifice considerable of the energy in the process of transmission. It is possible in case of such a plant far removed from the house to have remote control which may serve to close down and start up the plant by the simple operation of a switch or of a push button.

CHAPTER XI

ELECTROTHERAPEUTICS

HOW wonderful it seems that there should be so many new possibilities in nature, and that as soon as a new source of energy is discovered it meets the almost immediate reception of the scientist who aims, often slowly, however, to make practical application thereof. Many times we are startled at an application in some field apparently remote to the field of the discovered phenomenon. So it was with the electrical energy of nature. Slow it was in coming under the control of man. For countless ages it had existed throughout the universe in unmeasurable abundance, but with not one iota more nor less than now exists. Yet, not until the middle of the eighteenth century were the shutters of this new electrical treasure house cautiously at first opened; but later the windows and doors were opened wider and wider and the great wealth made available to all. For many decades now the science of electricity has been spreading at a terrific rate and establishing new relations.

If the science of *therapeutics* had reached over into our territory of electricity only recently, the act would not have caused so much surprise; but, it is standard history that as far back as 1750 many cures of nervous afflictions were being wrought through the application of electricity. One might, then, correctly state that among the very first of

the useful applications of electricity was that in connection with therapeutics. At that time the *frictional machine* existed as a generator of static electricity—a process involving simply the rubbing of insulators. The frictional machine has survived even to our time as a generator for therapeutical purposes, although its usefulness has been superseded by the more efficient piece of generating machinery known as the *static induction* or *influence machine* described in the chapter on Static Electricity.

The specific forms of these generators for supplying the various types of electrical energy vary according to the requirement imposed upon them. Certain treatment calls for a unidirectional current of a steady value, whereas other cases require a low current and high voltage and others the reverse. Again, there are demands for high-frequency alternating current, although the alternating current of low frequency also has a place in certain phases of the work.

The influence static machine still plays a prominent part in certain types of treatment. The machine as a generator takes much space, however, and is very heavy. Yet its application is such that no other type of apparatus, which is designed in a more compact and lighter form, quite meets the requirements for use in the treatment. The galvanic cells, of varying numbers in series, serve to give a direct, steady-valued current and thus also afford an excellent generating medium. For sources of the alternating current the medical induction coil is most extensively used; but transformers may be also employed upon the ordinary alternating-current lighting circuit to

either step-up or step-down the voltage of the source. The high frequency sparks may be obtained by the use of condensers and Leyden jars in connection with some source of alternating current.

The generating units as above mentioned may be employed either as a direct effect in treatment or in a secondary way in order to obtain the desired heating or luminous, magnetic and electrolytic characteristics of electricity for certain forms of application. Patients are subjected to electricity in the many different ways, but all are directed to accomplish the desired result. To become proficient in his work the electrotherapeutist must make an intensive study of his subject and of the field covered thereby. He must be well versed in electrotechnology, have thorough knowledge of anatomy and physiology as well as of the science of life.

The art of electrotherapy, then, is that branch of electrical science which treats of the applications of electricity to disease. By the layman less is known along this line of electrical applications than of almost any of its other applications. The man with an ulcerated tooth or jaw now goes to the dentist or surgeon, but without knowing that he may be advised to take electrical treatment as the best procedure to save the tooth. In such a treatment the affected tooth is subjected to a current of electricity for a certain period of time at stated intervals of days. The uninitiated patient is often surprised to find after a series of these treatments that a serious and dangerous condition of the mouth has been removed; and perhaps, too, he will be surprised at the size of the bill since such applications are expensive.

The patient suffering with paralysis, perhaps, may be directed to the expert in electrotherapy for the desired treatment. A most careful diagnosis would be made to ascertain the affected areas of disease and to determine the extent of its ravages upon the muscles, nerves, and other tissues. Then the best treatment is decided upon to relieve the particular conditions. Perhaps electrodes are clamped to the affected part and a direct current of a minute quantity is passed through. Or it may be that a high frequency current may better meet the conditions. Sometimes the treatment is wholly by application of surface electrodes from static machines such as *rollers*. The *static breeze* is often administered for physical fatigue and exhaustion. Nervous headaches are invariably relieved by its application. At one time the author had a most severe headache which for days persistently continued despite the ordinary method of attack. Happening to be in the office of a noted electrotherapeutical expert, and mentioning the malady, the *static breeze* was administered with most fascinating and decidedly positive results. The patient in these instances is required to sit upon a chair mounted upon a metal platform. This constitutes one electrode, while the other is in the shape of a canopy, placed directly over and near the head. As the static machine is set into motion the most refreshing sensation of a breeze begins, the hair seems to be floated lightly upon the head and a stimulation of most soothing application affects the nerves of the upper portions of the body. Furthermore, the tiny sparks that are caused to pass like a rustling of dry leaves, causes the generation of ozone, a stimulant, purifier, and

deodorant of the atmosphere. The aggregate of all these many subsidiary effects creates a cure and a confidence of no little importance to the doctors. Very often the patient of timid and retiring instincts finds that his nerves, which may be supersensitive, revolt against the appearance and noise of the equipment. Until confidence can be gained or restored in these cases little hope of success from the electrical treatment can be expected. Many times one treatment by the *electrical breeze* will suffice to assure the patient that the bark of the treatment hurts worse than its bite.

In addition to the described knowledge of electricity, anatomy, and physiology, which are fundamental requisites, a practitioner is by no means fully equipped until a knowledge of *materia medica* has been acquired in order to give the information relative to pharmaceutical agents necessary in abnormal conditions of treatment. The most satisfactory results of electrical treatment, thus, are usually gained only in conjunction with the other customary aids and benefits. Many individuals, however, still unreasonably cast aside the acquired facts and science of materia medica with its recorded benefits for a new form of treatment which robs the former of its dignity and prestige. Such new treatments are to be given skeptical receptions until certain facts establish their reliability. It is most generous as well as reasonable, however, to assume that the good points of the many various roads of approach to the Mecca—Wellville—may be appropriated into one combined treatment for the most rapid and satisfactory results. Such should be our attitude in regard to the treatment by electrotherapy.

It now lies beyond doubt and question that the judicious application of electricity, as an expert practitioner of electrotherapy can administer it, is capable in certain types of cases to restore normal conditions. Furthermore, certain medicines can be introduced to the local areas through external application with far greater success than with internal application, since immediate local effect is secured.

In order that intelligent application of electricity may be rendered to the disease or affectation, it is necessary that the practitioner may know several features of utmost significance. He must know that a diseased condition really exists, and, in case it does, when the curative process should be discontinued because of sufficient treatment. That is, he must be able to recognize the diseased condition as well as the restoration of healthy functioning. It is a well-known fact that in certain diseases either artificial or natural stimulation may cause harm, while in others the stimulation of diseased portions of the body is helpful in the promotion of health and well being. Thus with the proper knowledge at hand, it is quite true that electrical treatment may be locally given, so that only those portions of the system which demand treatment may be affected. Electrical treatment is no charlatan device—a cure for all ills—although many quacks force such ideas upon the public. These resort to such treatment with the hope that through the art of psychology they may effect some cures, and by the law of chance still others, recognizing that nature herself really accomplishes curative procedure continually by the natural performance of her laws. Quack doctors of medicine have had their

"heyday" in the profession of materia medica through the dispensing of the "gunshot remedy." Here many drugs were compounded of the various ingredients represented in the respective formulas for each of the principal prevalent sicknesses, with the hope that at least one of the ingredients would effect the desired result. No consideration was given to the harms and disorders that might result from the use of those ingredients that were not specified for the particular disease. Stringent legal enactments have since then made it a crime to administer to the sick except upon having completed the proper training as indicated through the possession of a diploma from certain authorized schools or institutions.

Protection of such a nature should be equally, if not even more rigidly, enforced in the case of electrotherapeutical treatment than in the case of the materia medica. The public should also be instructed and advised in such a way that they will not ignorantly apply the many instruments which are rendered so convenient for home use and are advertised as capable of curing all diseases by turning on the electric switch. The law should clearly expose the bona fide results of sufficient practice with these patent devices to serve either as a recommendation or a condemnation of the instrument. Certificates of cure may be reliable enough, but, unfortunately, the failures of the practice are not recorded by certificates of death.

As previously stated, among the electromotive force generators used in the field of electrotherapy, the galvanic cell affords a method in extensive use. It is desirable to have the battery portable and therefore light of weight and small in size. The

use of the zinc-silver electrode cells immersed in silver-chloride and ammonium nitrate electrolyte gives a relatively high voltage per cell. The cells may be made in long cylindrical tubes called *test tubes*. Such batteries suffice and give satisfaction for small current requirements. By connecting such a system in series, a voltage of 100 to 200 volts may readily be obtained.

For certain uses, particularly cautery work, storage batteries are required, which may be used in conjunction with a resistance in series with the

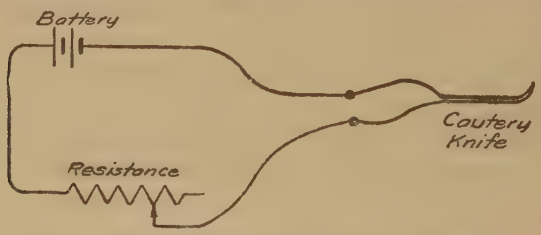


FIG. 192.—CONNECTIONS FOR A CAUTERY INSTRUMENT

circuit as shown in Fig. 192. Such an arrangement of resistance mounted on a control board forming a part of the battery circuit gives complete control over the flow of current and, therefore, the uniform and proper degree of heat required for the cauterizing instrument. Simplicity must be the dominant characteristic of such units in order that no errors may occur in the applications by the operators. All currents drawn from any battery system for use in this work have been given the name, in the technical nomenclature of the profession, galvanic currents.

No device is so well known by the public because of its long association with the medical profession

as the induction coil. Perhaps one may remember having played as a child with the medical coil—to find that, when the hand-grip electrodes were held and the coils started, he would be forced to grip the electrodes tighter because of the resulting muscular activity. The muscular contortion may even have been very pronounced if the current was made too strong. Sometimes, a quarter of a dollar placed in the bottom of a glass jar of water would repose there most temptingly throughout the evening party, until some one more fearless than the rest would defy the electric charge of the water and remove it.

The action of the induction coil has been heretofore explained in the section on Ignition. The coils there employed are of the small vibration type used to produce the high voltage necessary to cause a spark to jump across the gap in the spark plug. The vibrator is invariably operated by the magnetic principle. In the medical coils, many devices are employed to produce the make and break. In some types, the vibrator is actuated by the magnetic action, while in still others various devices are used such as mechanically operated interrupters, electrolytic interrupters and the like. These devices are used simply to produce *make* and *break* of such a nature as to cause the highest possible voltage to be produced for the least outlay of material as well as to give entire satisfaction in operation. These coils may be operated from the 110-volt lighting circuits, where it is direct current, or it may be from a battery source. The current on the high voltage side, called the *secondary* as in the transformer terminology, is referred to in the electrotherapeutic vernacular as *Faradic Currents.*

Such currents are always alternating, whereas the direct current from battery source, as heretofore explained, has been denoted as *Galvanic Current.*

The application of induction coils in the general field of electrotherapy is most extensive. Aside from its use in direct application as a curative agent, it is employed as a generating source for the high voltage energy required for the operation of X-ray tubes in both examination and diagnostic work and in the treatment of certain classes of disease by this recently applied process.

The size of an induction coil is usually rated by the length of spark it will produce between a couple of electrodes in air to which the secondary side is connected. If the voltage is high, it may give a spark across an eight-inch gap or even ten-inch. Coils have been made to give a spark over six feet long. Furthermore, in the operation of the X-ray tubes, the spark must have considerable energy behind it. The amount of this energy may be readily determined by inspecting the spark. A thin, blue-streaked spark indicates a feeble and weak energy transmission. The large, bright yellow spark resembling a flame, however, has the necessary power behind it. Such a coil is essential in the operation of the X-ray tube to give the sharp delineation necessary for locating and determining the nature of fractures, of foreign particles, and of types of growth. For the curative application, it is not necessary to have this degree of sharpness and yet it is advisable to have sufficient power to give control over the rapidity of the treatment. The use of the X-ray will be considered in following pages of this chapter.

The earliest type of electric generator used in the electrical treatment of disease, as has been explained, was the friction and induction machine for producing static electricity. The static generator was formerly used to excite X-ray tubes and to produce nearly all the high voltage functions, but now it is practically extinct and is seen only in the offices of the old-time practitioners, who keep them more for the sentimental associations than for utilitarian purposes. The induction coil has almost wholly replaced the static machine because it is so much more compact, convenient, and satisfactory in operation and because it can give a higher amount of power than any induction static generator built. The current from such a machine has been termed by the electrotherapeutic nomenclature *the Franklinic Current* to differentiate it from the *Galvanic* and *Faradic Currents.*

The transformer is another type of electrical apparatus used extensively in electrotherapeutics. It is employed occasionally for purposes similar to those of the induction coil, that is, for the production of high voltages where the primary side has only available alternating current rather than batteries which give only direct current. As is true in any ordinary transformer, in this machine, too, by placing many more turns of wire in the secondary side than on the primary side, the secondary voltage will be relatively higher than the primary voltage in that same proportion. Other uses of the transformer, however, lie in its readily adjustable voltage on the secondary side for direct application to the patient in the curative process. Of course, the physical design of such a transformer would differ radically from that of the com-

mercial transformer. Such a transformer may be seen in Figure 193.

The physical apparatus for use in this field of electrotherapy has been briefly treated and the sources of current enumerated and explained sufficiently to identify them. As yet little mention has been made of the effects of the electric currents in

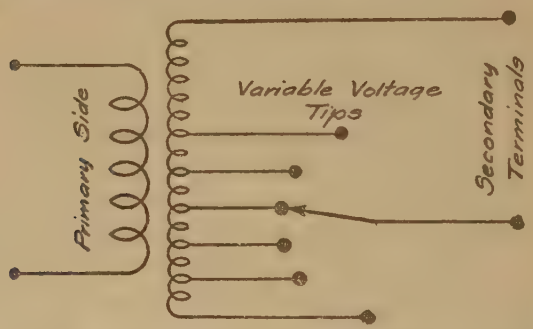


FIG. 193.—TRANSFORMER EQUIPPED WITH VARIABLE VOLTAGE TAPS

their passage through the human body, nor has anything been said of the nature of their curative properties and functioning. Although space and time will not permit any extensive explanation, a few remarks about the general characteristics of the currents as they pass through the body will be given.

There are four different effects caused by the electric current in its transit through the human body. These may be classified as follows: First, *electrolytic;* second, *magnetic;* third, *asmatic;* and fourth, *cataphoric.* The ordinary *electrolytic effect* in the body as the current is passed through apparently is of little importance. The same is true of any magnetic effect upon the body. The body has

been subjected to most intense magnetic fields without any noticeable physiological influence. Even such a delicate organ as the brain has been placed under concentrated magnetic fields of great force without harm of any kind. The important effect of the passing current lies principally in the so-called *cataphoric functioning.* It has been previously explained in considerable detail how the passage of an electric current in an electrolyte causes the movement of the particles called the *ions,* which are of two kinds, *positive* and *negative.* The positive ions are migrated with the electric current whereas the negative ions are carried in the reverse direction. As electrodes are placed upon portions of the body and a sufficiently high electromotive force is supplied to cause a current to flow, an action results which produces a decomposition of the tissue of the body and of the intermediary fluids to the electrodes. And since there is an actual movement of the ions between the electrodes in the body, it should be possible, as previously alluded to, to cause medicinal substances to be carried from the outside of the body to the interior portions by the process of ionization. Such treatment places the medicine directly in the locality requiring the treatment and is called *cataphoretic medication.* It constitutes one of the important branches of the subject of electrotherapy at the present time.

The skin of the body is a most effective insulation covering against the flow of electric current. When electrodes are placed upon the body, sponges or other absorbing material should first be saturated with some salt solution in order to render as high conductivity as possible. Any medication application should be placed upon the skin under the elec-

trode and the cataphoresis process will then be carried on.

The electric current in passing through that portion of the body lying between the electrodes will have an action imposed upon the tissues which will be dependent upon the magnitude of the current and its direction of flow. The passage of the current will cause accession of fluid substances in certain parts, whereas a depletion will result in other parts by the process of migration of the ions. By properly applying the current, those parts which are depleted of the substance of which they should have a normal amount may be made complete by removing an excess from some other locality, in which case the normal condition is restored in both localities and the healthy condition is established. The danger of ignorantly or carelessly applying the process, however, may here be clearly seen in that the abnormal conditions instead of being removed may be greatly augmented. The type of current applied in this direct application also has great bearing upon the treatment which should be given. This decomposition of the tissue of certain parts may be carried to its maximum effect by the use of the galvanic current. Since this is a constant or at least unidirectional current, it produces a maximum ionization or decomposition effect. In the case of the alternating current or Faradic current, the engorgement and depletion of the parts is not carried on as before. The process here involved is sometimes most complicated and the desired beneficial results are obtained through a maze of performances the reasons for which are not established. The results come directly from the experimental procedure. In electrolytic work, it is known that

certain processes which take place by a current flowing continually in one direction will not return to the previous state by reversing the direction of the current. Such processes are said to be non-reversible. Sometimes a certain product may be accumulated by passing the current first in one direction and then in the reverse direction. An alternating current, therefore, may produce most peculiar results in its electrolysis. Furthermore, its results are different for the various kinds of materials upon which it acts. Its applications to the body, therefore, produce results in certain types of disease but are inactive in other types.

In taking up a discussion of the X-ray in its application to therapy, some ideas of what the X-ray phenomena really are should be given. In previous chapters it was shown that what we call *light* is simply a physiological interpretation of a physical quantity. In other words, an organ that is known as the eye and its associated members is so constructed that it is capable of receiving certain disturbances in the all-pervading æther of space and giving to us the impression of light—perhaps it is a red light, perhaps yellow, or the like. Furthermore, light from the sun may be detected by another organ of the body, the skin. It intercepts the radiation from the sun which comes to us by virtue of the energy carrier, the æther, and by the interception of its heat is transmitted to the nerves. Excessive exposure to the sun changes the structure of the skin and we say that it is *burned* or *tanned.*

X-rays, which were discovered and applied in useful ways to therapy by Professor Röntgen, have many characteristics in common with the

ordinary light of the sun or artificial bodies. It is conveyed by means of the mysterious and evasive something known as the *æther of space.* It differs from the electromagnetic waves of radio communication, from the heat waves, and ordinary light waves only in the length of the waves. Light waves seem short when we realize that in a second many millions of them come to us; but in the case of the X-ray they are so short that the light waves seem of tremendous length in comparison with them. They are so short that as yet no instrument sufficiently sensitive has been devised to measure them. The wave length and the frequency have thus only been estimated. The waves because of their high frequency seem to be powerfully *actinic,* that is, they possess *the power* of influencing photographic plates. Ordinary light does this to a certain extent, ultra-violet light accomplishes it to a still higher degree, while X-rays have even a more pronounced impression upon the sensitized silver salt films.

The X-rays have been found to give severe burns which are identical in nature with the sunburn, only differing in the degree of the action. The operators must take precautions against exposure to the X-rays in order to avoid the serious effects of the burns. It takes a period of from nine days to two weeks for the burn to pronounce itself, which it does in a most vicious manner, expressing itself as it most often does through cancerous affectations. These burns are not mere surface and dermatitis eruptions, but rather penetrating sores of depth and severity. One substance that effectively screens the X-rays, as iron screens the magnetic lines of force, is a sheeting of lead to the thickness of one-sixteenth of an inch. Otherwise,

it is the most peculiar property of these rays to penetrate nearly all substances. Just as rays of light pass through glass and water because they are transparent to visible light, so do the X-rays pass readily through the sheets of most metals, woods, flesh, and the like, all of which are transparent to X-rays. As a piece of pasteboard or other opaque object effectively precludes the passing of

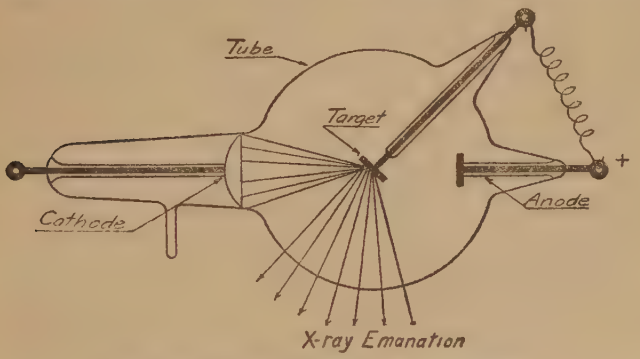


FIG. 194.—X-RAY TUBE OR GENERATOR

light, so also is a sheet of lead of sufficient thickness opaque to X-rays. Because of this peculiar property of penetration, X-rays have come into use for therapeutic treatment, analysis and diagnosis.

The generation of such rays was long ago discovered by Sir William Crookes, and his tube has ever been the principal generating equipment. This tube, as shown in Figure 194, has an *anode* and a *cathode* (positive and negative terminals respectively) to which the terminals of either a static machine or an induction coil is attached. The tube is highly evacuated of its air and any foreign gases. The electrodes within are made of platinum, although now, because of the relatively high price

of platinum, tungsten has found extensive and satisfactory use. The cathode is formed like the concave or inner surface of a sphere so that it will focus the electrical discharge called the *cathode stream* upon the anode, sometimes called the target, which as you may observe is placed at any angle which faces a clear and unobstructed section of the glass tube. As the high voltage is connected to the terminals of the tube and the *cathode* or *electron stream* is caused to play or impinge upon the platinum or tungsten target, it has the peculiar property of setting up these short wave length disturbances in the æther which are known as the X-rays. During the operation of the tubes a yellowish-green light is given off and the target often becomes heated to a cherry red because of the intensity of the electron bombardment. Due to the intense power of penetration, the focussing of the cathode stream upon so restricted a spot on the target causes a hole to be burned directly through it. The intensity of the X-rays given off vary with the degree of the vacuum of the tube, the temperature and the nature of the applied electromotive force. For best results the vacuum should be arranged for some variation, the voltage should be capable of control and sufficient power should be available. Lead shields are quite advisable when located so as effectually to protect the operator from the deleterious rays and their burning influence.

The apparatus is used for three purposes, as follows: first, for its therapeutic purposes, second, for its radiographical purpose; and third, for visualizing opaque bodies by use of the fluorescent screen. In the therapeutic treatment, the use of

light, ultra-violet rays and X-rays are most beneficial, since the rectification of the diseased tissue is caused by a readjustment of the existing cells and the further fostering of new growth rather than by the destruction of these cells. The *pathologic tissue,* or in other words, the *diseased tissue* of the body is composed of most complex and unstable molecules which collectively make up the cell structure of the lesion or disruption of tissue. Very little energy is required to be added to this system to cause a readjustment of the atoms constituting the molecules of the cellular structure. This rearrangement of the atoms of the cell results in a new cell of different nature. Such chemical actions are demonstrated by the appearance of sunburn, tan, freckles, and the like. The X-rays cause more severe and destructive lesions than does the sunlight, probably because of its greater strength of actinic properties.

In regard to the radiographic characteristics, the X-rays have a most powerful excuse for their existence. Due to the mysterious powers of penetration of the X-rays, they readily pass through the flesh and tissues of the human body, but not through the bone portions. Therefore, if a photographic film be placed so that the member of the body lies between the plate and the X-ray tube, the rays as they pass through the flesh and not through the bone would cause a shadow of the bone to appear upon the plate since that portion of the plate is not acted upon by the rays, whereas the other portions of the plate are chemically changed by the actinic rays. When such a plate is developed, the outline of the flesh portions show lightly in a gray shading, whereas the bone and opaque parts appear black.

Such photographs are useful in locating fractures, foreign particles such as nails, bullets, and the like that find their way by various means into the flesh. The application of such radiographs are each day increasing. The photographing of the teeth by the X-rays is a newly devised feature which is meeting with wide success. The interpretation of such photographs is a matter requiring experience and knowledge. The photographs are useless even after they are taken unless an analysis is made that gives the correct meaning to the findings. Ulcers, abnormal growths, and decayed portions are thus often located which would otherwise escape observation and which in many cases are the dominant cause for weeks or even years of ill health and suffering.

The third case mentioned above is that of a visual observation by the means of a fluorescent screen rather than a photograph of any part of the anatomy under discussion. As the reader has probably known before, there are certain minerals, among which are *barium* and its compounds, which are susceptible to light rays in a peculiar manner. As the rays fall upon these minerals, they are caused to glow and give off a light of different wave lengths, depending upon the mineral. This glowing of the mineral may be caused not only by visible light but as well by ultra-violet light and even X-rays. It is because of this latter effect that we are enabled to make visual inspection, a feature that gives oftentimes a quick method of determining some condition, and saving the time of taking a photograph and having it developed. The fluorescent screen most commonly employed for this purpose is a bario-platinum cyanide screen. A pasteboard or other material, transparent to the mineral com-

pound, is saturated or covered with the fluorescent material on one side. This side is usually protected by a boxing narrowed down to fit closely to the eyes. A hand interposed between this screen and the source of X-rays will throw a shadow of the bones upon the screen which becomes visible as one looks through at it. The barium salts glow where the X-rays fall directly upon them, but where the opaque bone prevents the rays from impinging upon it, the bone appears upon the screen as a shadow. Any fracture, bone growth, or foreign particle residing inside the hand would be clearly portrayed by this means.

In the treatment of the diseased tissue of the body, the medical operators and experts differ among themselves as to the best pursuit of operation. One worker has one method of attack while still another has his own individual technique. In almost every case, however, of the most successful and prominent workers along this line, all agree that the idiosyncrasies of the individual patient must be considered and studied first before a satisfactory course of treatment can be administered. In all cases the patient must not be subjected to the exposure of the rays in such a way that any serious burn will occur. The treatment is usually applied five to ten minutes at first, then repeated after a week, and then again after a couple of weeks. By studying the conditions during this time, a fair idea of the susceptibility of the patient may be obtained. Then succeeding applications may be administered with a degree of assurance that no detrimental effects will result from overexposure. The idea of the exposure is not to burn the lesion that already exists but rather to supply the energy necessary to

cause a rearrangement of the unstable molecules of the cells of the tissue. Periodic application of the X-ray stimulates the change that occurs and fosters the return of the cells to a healthy condition. An alternative treatment is to burn out the wound or lesion by cautery and thereby destroy the diseased tissue entirely. In place of this destruction, new tissue will be caused to grow. The process, however, is slow and greater drain must be made upon the human system, since the energy to restore the diseased portion to a healthy growth must come from within rather than from an external agent.

PRINCIPAL USES OF X-RAY

As already explained the use of X-rays as an agent in medical treatment is coming into more and more favor as its principles are becoming better known to the scientists in this field of activity. In the field of medicine and surgery, the use of the X-ray for diagnosis overshadows all others.

Detection of the presence of pearls in pearl-bearing mollusks is a novel use of the X-rays. Such examination may be readily made by holding up to the exposure of the X-rays the oyster or other pearl-bearing organism. In this procedure no harm is done to the mollusk which may be replaced in the water in the event of no findings and given further opportunities to produce the valuable gems.

A most recent application of X-rays in the customs examinations of baggage for smuggled articles is a use serving an important rôle for the government protection. Clothing may be readily examined for jewels and diamonds. Trunks and other types of containers may be examined for false compartments holding smuggled goods.

RADIO STATION, NEW YORK "TIMES"

When the operator is receiving messages from one station, the automatic recording set at the right may be employed to register messages from another on phonographic cylinders

Copyright, Keystone View Co.

A PICTURE TRANSMITTED BY TELAUTOGRAPH

Fountain pens, shoe heels, and the many other notorious hiding places of jewels can be readily and quickly inspected for their contents.

The X-ray has been used and applied as the most effective means of sterilizing certain kinds of foodstuffs, tobacco leaf, and the like. The application of the X-ray to any product of this kind without doing any harm to the product itself, regardless of how sensitive it may be, will kill the spark of life in any microorganisms, eggs of worms, or of other parasitic growths.

Previous explanation involved the fact that the penetrating properties of X-rays were so great that even metals of considerable thickness become transparent to them just as glass is not opaque to ordinary visible light. This property of X-rays to make visible the structure of metals, serves the purpose of disclosing any imperfections, blowholes, and other types of undesirable faulty microscopic structure in the metal.

The detection of spurious diamonds by subjecting the stones to the X-rays constitutes a new use of no little significance to the jewelers and the dealers in stones. The pure and true diamond appears more clearly transparent than do the false stones or artificial imitations. From the various uses to which the X-rays are put it may be realized to what importance this field of electricity may ultimately rise.

CHAPTER XII

WIRELESS COMMUNICATIONS

AT the close of the last century (1899) Signor Marconi, the brilliant Italian scientist, transmitted messages in the Morse code from the cliffs of England across the channel to France, a distance of about thirty miles. The event was heralded as one of the greatest of the century, and, indeed, a new epoch had been established in the records of time.

Consider how wonderful an accomplishment it is to convey messages with the speed of lightning across the intervening distances without the use of connecting wires. The process, too, is quite simple. At one locality instruments are used to transmit or impel the system of dots and dashes. The resulting succession of disturbances, in that universal medium called æther, carry the message with silence and speed to a second system of instruments at a receiving station.

Back in 1886, Heinrich Hertz began a most notable and famous set of experiments in which he investigated the elements of space transmission of signals. He produced the necessary æther disturbances or waves for radiation into space. These he detected by certain receiving instruments after they had been transmitted through heavy walls of rock and other intervening material. He studied the fundamental laws of electromagnetic waves and, in fact, made exhaustive analysis of this field

of new potentials. It required, however, the more practical mind to take the results of such experiments and frame them into tangible form so that the entire world could be benefited. This fact met response in the inquiring and fruitful mind of the young Marconi, who soon acquired the lead in translating the more abstract truths of Hertz into a concrete form which soon startled the world. Within two years after accomplishing the feat of the English channel, he gained a greater distinction by sending the first signal by wireless radiation which tied together the new and the old worlds through a receiving station at Newfoundland and a transmitting station at Cornwall, England. Since that time rapid progress has built up an art of a high order of perfection, until now the uttermost parts of the earth have been brought into almost instantaneous communication with each other.

The wonderful æther of space which fills the universe is, as a result of various causes, in the most turbulent and constant agitation and vibration. It serves as the carrier which brings to us the light and the heat of the sun, the light from the most distant star, and the electromagnetic disturbances of the sun. These phenomena agitate the æther in various ways. The resulting vibrations that throb constantly in this æther are of *wave lengths* which may differ enormously from each other in value. It is known beyond doubt that the electromagnetic waves that radiate from the discharge of a Leyden jar or any condenser differ from the phenomena of light or heat only in the length of the waves. The following varieties of waves are probably all simultaneously present in the vast depths of æther space. First, there are

the electromagnetic impulses arising from a magnetic unbalance in the sun. These waves are probably in some instances more than one million miles in length or have a frequency of occurrence once in every six and one-half seconds. Second, there are the electromagnetic waves set up by flashes of lightning. These are much shorter in length, being estimated at approximately eleven thousand miles with a frequency of about seventeen per second. Third, there are the radio or electromagnetic waves produced by the devices of man. Such waves may be as long as eighteen miles in length and have about ten thousand vibrations per second. The waves set up by a pint size Leyden jar may be as short as fifty-four feet in length with a vibration rate of eighteen million waves per second. The shortest wave produced by electrical methods is only two and a half inches long, and the frequency of vibration is four billion eight hundred million per second. Fourth, disturbances of the æther which we generally recognize as heat, vary between the limits of twenty trillions of vibrations per second for the lowest sensations of heat, and as high as three hundred trillions of vibrations per second for the highest sensations of heat. Fifth, as the period of æther vibration becomes still less, the wave lengths that affect the organ of sight are reached. These vary from about three hundred and seventy trillions to seven hundred and sixty trillions of vibrations or waves per second. Sixth, waves of still shorter value, known as ultra-violet light and X-rays, have vibrations from 800 trillions to about 8,000 trillions of vibrations per second.

The æther about the surface of the earth, even in its constant and complex vibration, is capable of

transmitting the messages from the innumerable radio stations without interference one with the other. Such miraculous accomplishments seem almost beyond human conception. Yet, the apparatus required in order to transmit and receive wireless communication is most simple and relatively inexpensive. In fact the entire apparatus may be of home construction. The æther waves are originated by causing a flow of current of rapid oscillation to play in a system of wires held high in the air and called the *aerial* or *antenna*. The radiating waves emanate from the antenna into space and at some distant station the effect of these æther disturbances makes itself known in the receiving equipment of which the detector is the sensitive ear. Other stations may also listen in on a message. There is thus not the privacy of communication that one enjoys on the individual wire of the wire system of communication. The æther of space is the one great conductor for aerial communication. It is quite possible, however, for many stations to communicate simultaneously without interference. Two stations may attune themselves to the exclusion of the other messages that are circulating between other stations.

The subject of radio theory involves most intricately the principles of *sympathetic vibration*, which has received some attention in a previous chapter, but which will be briefly considered at this time. Consider a piano with the loud pedal depressed in order to free all the wires of the instrument as a receiving device. Sing a musical note in the room and you will find that one certain string on the piano is vibrating and reproducing the identical note. Sing a lower note and, to your

amazement, you will find a string now vibrating to reproduce this lower rate of vibration and that the previous one is not affected. Such a phenomena is called *sympathetic vibration.* The voice set the air into vibration, but the number of vibrations is

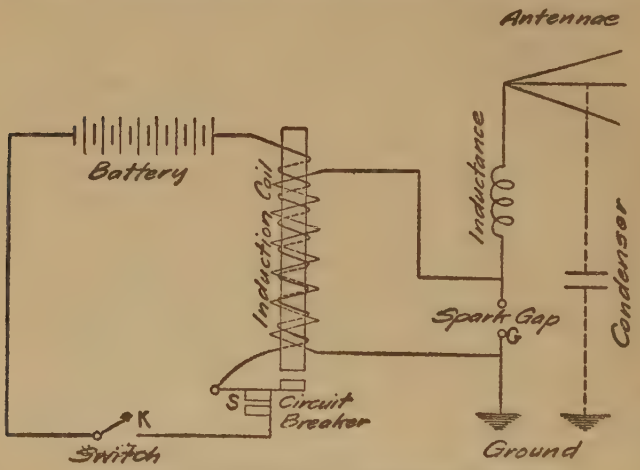


FIG. 195.—MARCONI TRANSMITTING SYSTEM

dependent upon the pitch of the note. These waves as they impinged upon the various wires of the piano affected only the one whose natural rate of vibration was the same as that of the air. The small energy of the impinging train of waves sufficed to start the string into vibration and to amplify its motion as each succeeding wave struck against it. Any wire of different vibration rate would at times have the energy of the air waves opposing any tendency for the wire to respond. Therefore, in dealing with the heavy medium of air, we can see how an instrument may be made to respond to transmission of waves by a process of attunement or sympathetic vibration.

For simple illustrative purposes let us consider the diagram of an early form of Marconi transmitting system, as shown in Fig. 195. An equivalent of the secondary circuit is shown in the simplest form in Fig. 196. The circuit is observed to be formed of a condenser, an inductance and a spark gap between two small balls or contacts. Of course, the wire of this circuit contains some resistance. Such a circuit is said to be a *high frequency* or *oscillating electric circuit.* If a spark discharge is caused to occur across the spark gap, due to impressing a high voltage at the spark gap terminals, as shown, the charge in the condenser oscillates back and forth through the circuit at a speed or frequency depending only upon the size of the condenser and the

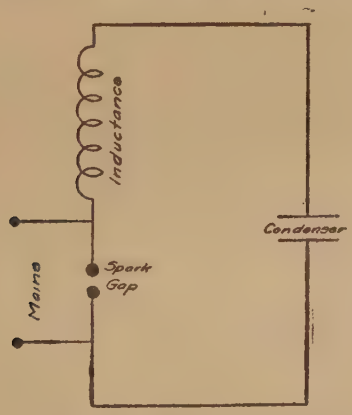


FIG. 196.—OSCILLATION CIRCUIT

inductance. The energy in the circuit is consumed or frittered away first, in the form of heat in overcoming the resistance of the circuit and, secondly, through radiation of the electromagnetic waves. The frequency of the oscillation of the energy of

such a circuit depends in no way upon the frequency of the sparks at the spark gap; but rather upon the constants of the circuit (capacity and inductance) only.

The antenna may be formed in many different ways, but in any case it consists of several wires held aloft by poles. The antenna forms with the earth a condenser as shown in the dotted line construction of Fig. 195. The wires of the circuit have an inductance of their own, although a separate coil of several turns may actually be placed in this circuit. The simple operation of the Marconi transmitter is as follows: As key "K" is depressed the primary circuit of the induction coil is completed through the contacts at "S." The secondary coil having a great many turns of wire has induced in it a high voltage as the current builds up in the primary circuit. This high secondary voltage becomes great enough to break across the spark gap "G," and the energy which has been accumulating in the condenser now readily discharges across the low resistance of the arcking gap and charges the condenser in the reverse direction. This reverse charge then causes a reverse flow of current and like a released spring oscillates back and forth in the circuit at a constant frequency, but with ever diminishing energy. That is, the magnitude of the current is less in each alternation, although the frequency remains constant throughout. Such oscillations are said to be *damped.* As the core, however, of the induction coil becomes magnetized by the growing primary current, it draws the spring toward it and separates the contacts at "S," thereby opening the primary circuit and causing this current to decrease. The collaps-

ing magnetic field about the secondary coil, as in any transformer, causes the electromotive force to be built up in the reverse direction. This causes another spark discharge across the spark gap to continue the oscillation procedure of the aerial circuit. The make and break of the primary circuit may occur many hundreds of times a second. The

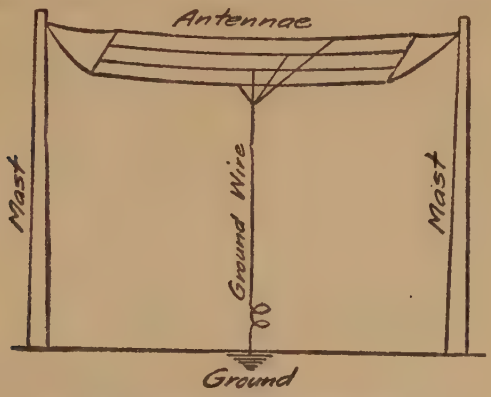


FIG. 197.—METHOD OF SUSPENSION AND CONNECTION OF AN ANTENNA

power that the oscillatory circuit takes up depends upon the value of the capacity in the antenna circuit, upon the square of the maximum voltage impressed upon the circuit, and upon the number of times the spark passes per second. For each spark passage the oscillation circuit reverses its current many hundreds of times, the number depending upon the circuit constants—the number of vibrations of this antenna current being many hundreds of thousands or even millions per second.

Fig. 197 shows one very common type of antenna. Where the distributed inductance and capacity of

the antenna wires constitute the elements of the oscillating system, the wave length corresponding to these constants is called the *fundamental wave length* of the antenna. The wave length may be increased by placing inductance coils in series between the aerial and the ground. By

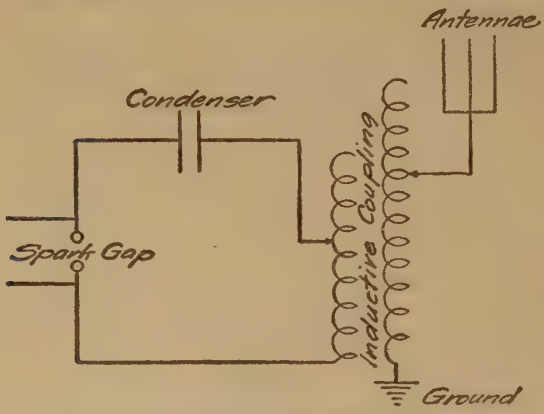


FIG. 198.—GENERATION SYSTEM FOR HIGH FREQUENCY RADIO WAVES

replacing the above inductance by a condenser the natural wave length of the aerial may be shortened.

In practice, however, it is objectionable to have the spark gap, which does have considerable resistance, directly in the antenna circuit. It is customary to excite the aerial system by the high voltage obtained from the step-up side of a transformer which may be either directly coupled (that is as an autotransformer) or inductively coupled (as any ordinary transformer). Fig. 198 shows the connection for an inductive coupling which is most satisfactory for general purposes. The oscil-

lations in the aerial circuit may be made to have the same frequency as those of the spark circuit by adjusting the value of either the inductance or the capacity in the primary circuit. For this purpose the condensers and inductance coils are made to have variable adjustments. When such equality of frequency or vibration rate of the oscillating currents in the two circuits are obtained, the two circuits are said to be in *resonance*. The product of the inductance and the capacity of the primary circuit would just equal that of the secondary circuit.

It is clear, then, that by tapping the operating key of the transmission system energy is caused to surge back and forth in the antenna, and thereby produce and radiate trains of æther waves into space which correspond to the dots and dashes of the code. All that is necessary then to complete the process of communication is a system to receive and detect these wave trains as they traverse the æther.

For this purpose of receiving a similar antenna is used. In fact, the same aerial system may be employed for alternating transmitting and receiving. The receiving antenna must be attuned to the same frequency as the radiation of æther waves; or, in other words, the receiving and transmitting systems must be in *resonance*. The wave length of the receiving system is varied by regulating variable inductance and capacity units until the æther disturbances or wave trains, as they sweep across the aerials, set up currents which are detected in a detecting circuit. Fig. 199 to Fig. 202, inclusive, show various types of receiving circuits found in common use.

In Figs. 199 and 200 the detector circuit is permitted no variation or tuning. All of this is done by the antenna system by means of the adjustable inductance and capacity. In Figs. 201 and 202 the detector circuit may be attuned to the antenna cir-

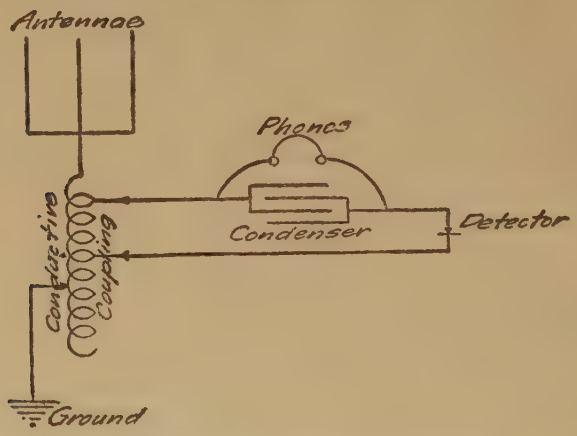


FIG. 199.—SIMPLE RECEIVING SYSTEM

cuit and the incoming signals. As the currents from the antenna oscillate in that circuit they affect the detecting or secondary circuit either by direct or indirect coupling. The detecting system is composed fundamentally of an inductance coil or coupling, a condenser, a detector, and head phones. The detector may be one of many different types. There are *coherers, magnetic vacuum valves,* and *mineral detectors,* all of which have played an important rôle in developing the field of radiotelegraphy. A very common type of detector, and one that has been used with great success, is the *mineral type contact rectifier.* This usually consists of a contact between a fine

wire and some type of mineral, among those commonly used being *carborundum, galena, iron pyrites, silicon,* and *molybdenite.* These contacts have the peculiarity of permitting current to flow in one direction only. The incoming waves of signals set up the oscillating currents in the receiving antenna in resonance with those of the transmission aerial, but in the detecting system these currents are allowed to flow in one direction only, so that a pair of head phones or a galvanometer may be used to convey the signals to the attention of the operator. The detectors have relatively high

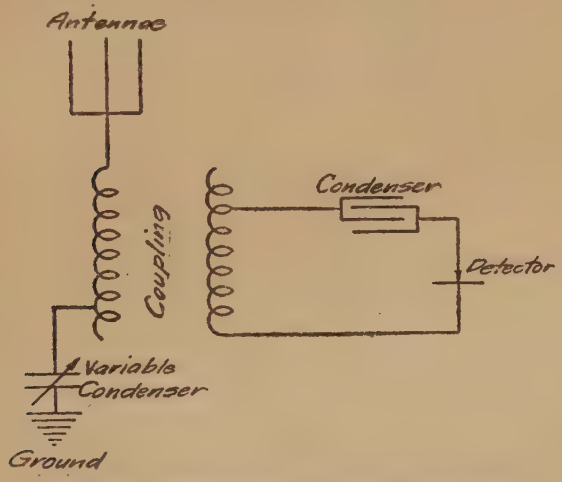


FIG. 200.—INDUCTIVELY COUPLED RECEIVING SYSTEM

resistance and are, therefore, placed in a separate circuit in order not to diminish the sensitivity of the system. For detecting the direct-current pulses, phones having resistances from one thousand to three thousand ohms are generally em-

ployed. As shown in the above cuts, the phones are placed across the small condensers which store up the energy of the direct-current pulse trains to be discharged later through the phones. If the spark at the sending station acts in a regular suc-

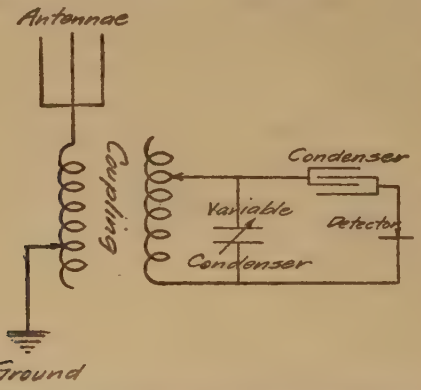


FIG. 201.—INDUCTIVELY COUPLED RECEIVING SYSTEM

cession, a clear musical tone is produced in the phones.

The coherers and magnetic detectors are for the most part relegated to the historical days of past experience. In nearly all systems now the use of the vacuum tube detector has superseded all other types because of much greater sensitivity, ease and assurance in operation.

The coupling between the primary and secondary coils may be close or loose, depending upon how much of the magnetic field of one links with the other. In case that most of the magnetic field of one coil links the turns of the second coil, the coupling is said to be close. In this case a peculiar effect is noted in that two different frequencies are

present. As the coupling is made loose the two different values of frequency tend to merge into one and actually do form a single frequency with a sufficiently loose coupling. This effect is highly desirable on long-distance transmission, since a longer range of sending results and in receiving the disturbing effects of atmospheric charges are eliminated.

For small sets the simple *stationary contact spark gap* is employed. Large power stations require, however, the use of either *rotary gaps* or *quenched gaps*. The current or power must be relatively great on long-distance installations and the spark gaps would be in danger of melting or rapidly deteriorating unless methods were employed to protect them. In the *rotary gap* many

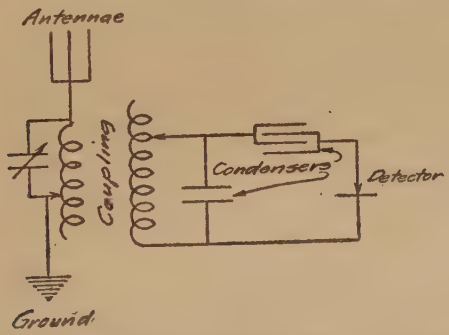


FIG. 202.—RECEIVING CIRCUIT WITH A CONDENSER SHUNTING THE COUPLING

contacts are mounted on a revolving disk, a process which affords ample cooling in the time intervals between sparks. In the *quenched gap* the spark is actually divided up into a series of short sparks between a number of insulated metal plates The cooling is very rapid. This gap is slightly

more efficient than the rotary type in its transmission of the generated energy into the antenna circuit.

Transmission of telegraphic communication may be divided into two classes, the one *day transmission,* and the other *night transmission.* The day transmission is more regular and more reliable. The sending is, furthermore, more satisfactory and much clearer over salt water than it is over land. This is accounted for by the phenomenon of absorption which takes place to decrease the energy of the radiation. It had been found that the absorption in transmission in the summer is also much greater than in winter. By measurement it has been found that the decrease in energy in radiation for one thousand meter wave lengths for transmission between New York and Washington is in summer about 70 per cent of that of the winter periods. It has been found that for short distances less absorption is experienced, and therefore stronger signals may be obtained by the use of short-wave lengths; whereas for long-distance transmission, wave lengths from three thousand to twenty thousand meters give better results. In overland radio dispatching for distances of 150 miles or greater, wave lengths should not be less than two thousand meters. The meter is always used for designating wave lengths. It is a little longer than the yard, or 39.4 inches.

Night transmission of radiotelegraphy is subject to most extraordinary irregularities and fluctuations. Little is known to account actually for these phenomena. At times, though, two relatively small stations have communicated thousands of miles apart during night periods. During winter months

the reliability of night transmission has been superior to that of the day.

ELECTRIC WAVE GENERATION

As we approach the subject of the generation of the radio waves, a natural division of the type of vibrations emitted from the antenna and radiated into the great regions of space should be made. It was stated above that the trains of waves of very high frequency rapidly decreased in amplitude as the energy of the oscillations frittered away in the antenna system, due to heat generation and to radiation of the energy into setting up the æther waves. The electric spark always produces *damped waves.* Furthermore, there are spaces or intervals between these wave trains when no energy is given off. If now a generating unit, instead of supplying the energy only at the beginning of a wave train, would give a constant flow of energy into the aerial system, waves of constant amplitude and continuous duration would result. Such waves or oscillations are said to be *undamped.* There are three distinct advantages for the use of undamped oscillations in radio communication: First, that the intensity of undamped waves, as they travel over the surface of the earth, decreases less rapidly than for damped wave trains at great distances; second, that the use of undamped oscillations permits a *sharper tuning* and enables a *looseness of coupling* at the receiving stations which reduces very materially the disturbances and interference difficulties of the atmospheric discharges; third, that as the waves are constantly radiating the energy may be distributed uniformly among them with a resultant decrease in the magnitude of voltage required for a given amount of

power over that necessary for damped-wave transmission. This results in a reduction of the amount of insulation required and permits a greater amount of energy to be sent out from a given size antenna.

The most generally adopted way of producing undamped wave generation is by means of *high frequency generators.* Those most usually employed in the high power service are the *Alexanderson* and the *Goldschmidt* generators. There are, however, two other methods of generation that are receiving cordial welcome known as the *Poulsen arc generator* and the *vacuum tube generator.*

During the past few years the General Electric Company has become active in researches along the line of radio communication. The demands of war service have undoubtedly reacted in stimulating this development. Their work has been so successful that it was found to be mutually advantageous to both parties concerned, the General Electric Company and the Marconi Wireless Company, to merge their interests into one company called the Radio Corporation of America. The advantages of close cooperation of the great engineers of both companies, where their efforts will be directed along narrower channels, should lead to improvements of the existing systems and the establishment of new methods that could not be accomplished through individual study.

This corporation has one of the most powerful plants in the world located at New Brunswick, New Jersey, in which is employed a 200 kilowatt Alexanderson generator to produce the radio waves used in transoceanic communication. The wave length used by this station is 13,500 meters. The antenna current is 400 amperes. This corporation has

acquired all rights to the Alexanderson generator, which was invented by Dr. Alexanderson of the General Electric Company.

The newest form of the above machine is now made in two standard sizes, one for wave lengths of 6,000 to 10,000 meters, and the other for wave lengths of 10,500 to 25,000 meters in units of 200 kilowatt capacity. Oscillation generators should possess the following qualities: First, produce a steady stream of sustained oscillations; second, give a pure form of wave; third, give steady and reliable performance; fourth, permit of economical and efficient operation; fifth, should be capable of manufacture in any desired power.

This Alexanderson generator operates on the induction principle, where both the field and the armature coils are stationary and the necessary variation of magnetic lines of force used to cut across the armature wires is obtained by the moving of alternate slugs of magnetic and nonmagnetic material near the field and armature coils. These moving slugs are the circumferential edge of a wheel which revolves at a tremendous rate of speed. The voltage produced varies from 100 to 500 and by the use of a very ingenious transformer steps up the voltage to from 2,000 to 3,000 volts, which is impressed directly upon the antenna system. The speed regulation on the Alexanderson generator is maintained as close as one-tenth of one per cent, or, in other words, it runs at a speed that does not vary under the operating conditions more than one revolution out of every thousand from the exact value.

The Poulsen arc is employed in some plants for use as a high frequency oscillation generator. The arc electrodes are made of copper for the positive

and carbon for the lower and negative one. They operate in a chamber filled with hydrocarbon vapor —the hydrogen being an excellent conductor of heat assists in cooling the arc. In large units the positive copper electrode is water-cooled. These arc generators are made in sizes up to 1,000 kilowatts.

Figure 203 shows how the circuit is arranged for the arc unit. It is excited from a direct-current

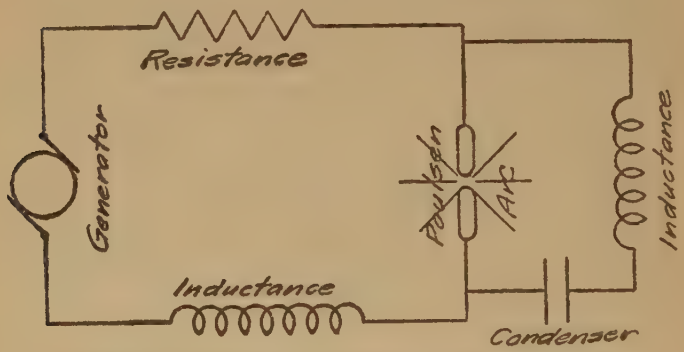


FIG. 203.—CIRCUIT FOR POULSEN ARC GENERATOR FOR UNDAMPED WAVES

generator through a resistance unit and inductance coil in order to smooth out any fluctuations in the supply of energy.

A type of oscillation generator that is being used to a great extent in radiotelegraphy and quite extensively in radiotelephone communication is the so-called *vacuum tube,* of which previous mention has been made. Thomas Edison first discovered the principle of the vacuum tube, but it was not developed as a *rectifier* or *electric valve* until a few years later, when Prof. J. A. Fleming made practical use of the device. It consists of a hot filament electrode heated from a four-volt storage battery,

and a grid between the filament and the plate—all inclosed within a glass tube exhausted to a high degree of vacuum. Commercial tubes of the Western Electric, De Forest, Von Lieben and Marconi types may be found to differ only in the arrangement of the electrodes and in regard to the voltage employed. They may be used in radio communication in four different capacities, as follows: *Oscillation generators, detectors, amplifiers,* and *modulators.*

The connection of a tube in a circuit for use as an oscillation generator is shown in Figure 204. The two circuits "I" and "O" are inductively coupled

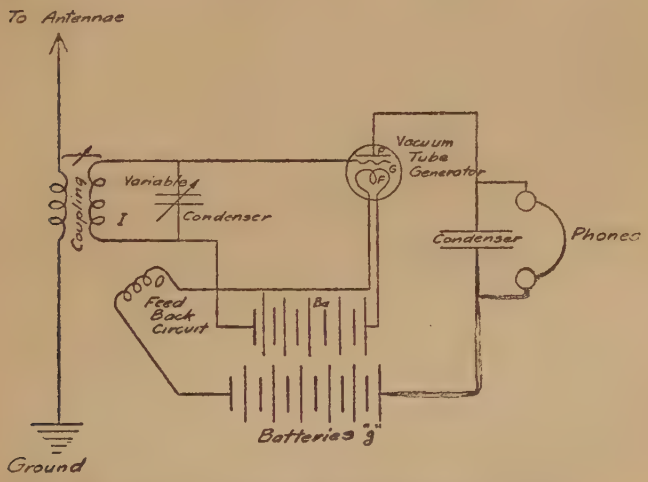


FIG. 204.—VACUUM TUBE GENERATING SYSTEM

to each other and jointly coupled by a variable loose coupling to the antenna system. Normally, the storage battery "Ba" causes a current to heat the filament and emit a stream of electrons to the plate because of the high voltage from the battery source or generator at "g," making the plate a positive

electrode to the negative filament. This means that a current of small value flows through the circuit of which "O" and "g" are a part. Any slight variation in the current flow of this circuit, however, acts inductively upon the coupled "I" circuit which sets up natural oscillations. These are impressed upon the grid which set up similar but amplified oscillations in the output circuit "O." These cause, in turn, forced oscillation in the input circuit "I," which again react upon the output circuit, and the alternating current thus builds up to some steady or constant value as determined by the characteristics of the tube. The alternating current produced in the output circuit "O" is not a pure sine curve, but is so distorted that a direct-current component is available, and may be read on the ammeter shown in the plate circuit. The output circuit "O" is oscillating and may have this electromotive force impressed upon the antenna system. By inserting a key in either the plate circuit "O" or the input circuit "I," any interruptions as dots and dashes will cause the radiating æther waves to be characterized by these pauses. Or by replacing the key by a microphone system having a mouthpiece as used in the telephone systems, a voice current may be superimposed upon the carrier waves as generated by the generator and the characteristic formations of the spoken words in the æther waves may be borne to the receiving station and there reproduced in audible speech.

The same connection as above shown for the oscillating vacuum may be employed as a receiving device, and it is then generally called the *heterodyne reception* or *feed back*, because of the input and output being in an inductive relation one with

the other. Such a receiving system is quite generally employed and is one of the best methods of receiving continuous wave communication. In operating as a *heterodyne receiver* of undamped waves the input circuit must be slightly out of tune with the signals as they come from the antenna in order that an audible "beat note" be given. This means

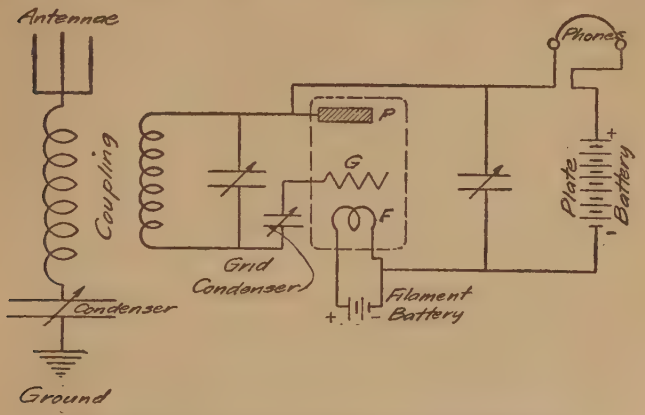


FIG. 205.—VACUUM TUBE OR AUDION RECEIVER

in simple language that the frequency of the voice or any method of tapping employed falls within the register of the ear, or less than eighteen thousand vibrations per second, whereas the generator incoming waves are several hundred thousand or even millions per second. In order that such signals may come to the range of the ear, one circuit must be made to differ from the other in its vibration period so that instead of hearing the individual high vibration rate, it is the difference of their vibrations that we hear, a process which is called the "beat."

In Figure 205 is shown a simple arrangement of the vacuum tube for detecting purposes only. Such

a connection will detect the damped waves of a spark system, but not the continuous wave transmission. By taking the signals from any vacuum tube receiver and conducting them through the transformers and to other tubes that are in *cascade* or *parallel* with the first, many degrees of amplification may be accomplished. The signals may be increased in intensity by such a method from twenty to one hundred and fifty times. By connecting a loud-speaking phone with a horn, like the old phonograph horns, to such a system of amplifiers, the conversational tones of a speaker hundreds of miles away may be made loud enough to be heard many blocks. During the past year such a device was equipped in Times Square, New York City, so that Secretary Daniels was heard by wireless many blocks as he gave a lecture on board one of the battleships at sea. The music of the orchestra likewise was transmitted in the same way with the volume of a dozen great symphonies in unison.

Space does not permit any detailed considerations of the numerous methods of operations and arrangements of the equipment. The vacuum tube advent into the field of radiotelegraphy and radiotelephony and wire telephony has truly wrought a revolution in the former methods. The present applications of this tube, though, will be insignificant when compared to what they will be in the future.

As soon as radiotelegraphy became a certainty and stations began to spring up here and there and the ships were equipped with it, attention was directed to the possibility of radio communication of the spoken word rather than in the dot and dash of the code. In a very short time, such communication became a certainty over short distances.

Improvements in the circuits and apparatus caused continual increase in the radius that limited communication. The great victory over distance was heralded in the fall of 1918, when the commander of one of the battleships 800 miles at sea was called to the phone and there recognized the voice of his wife as she spoke to him from a little town in New Hampshire. Her phone connected by wire with the powerful radio station at Arlington, Virginia, where the modulations of her voice affected the outgoing waves from the great banks of vacuum tube generators, which carried with most remarkable perfection the individuality of her voice, so that the commander immediately recognized it, although he had not been informed of the anticipated experiment.

Through the persistent efforts of the great men who have dedicated their lives to scientific research, the human voice can now be thrown within the space of a few seconds to almost any community over the civilized parts of the earth. Not only is radiotelephony successful, but it even surpasses in clearness and reproduction of the quality and modulation of the voice wire telephony. The highly elastic and practically weightless medium of æther responds and transmits without sensible distortion every slightest characteristic of the voice.

Stations of great power have been established at Paris, Arlington, and Hawaii. Other stations are being erected and equipped so that the darkest corner of the earth shall be tied by the human voice to the greatest center of industry. A complete layout of plants has been designed over the surface of the earth in order most effectually to affect the desired extension.

War time needs gave a great stimulus to the development of radiotelephony. The most able engineers of our government departments of science and research worked in cooperation with the skilled and practical engineers of our great electrical and industrial corporations. The ceaseless concentration of these great minds upon the one objective, to develop a system of communication to fit the special need of each department of the war program, succeeded in removing many of the limitations of the science of wireless and in establishing it upon a firmer and more nearly perfect basis, to say nothing of extending the application to an almost inconceivable degree.

At the vast training schools for the aeroplane service, the use of the wireless intercommunication for the planes from the ground afforded a means of direction and of coaching from points of advantage on the ground which saved many a youthful flyer from accident and death. The use of the wireless phone service between planes gave a ready method of issuing orders, of making formations, and of correcting errors at a time when the impressions from such advice would become fixed. These aeroplane sets were made in small self-contained units with a minimum of adjustments. The phones were contained in the heavy headgear used for the double purpose of excluding the deafening noise of the engine and to protect the head and face from the exposures of the various atmospheric conditions. The aerial consisted of a wire system trailed from the rear of the machine. The generating source for the direct-current potential was a small dynamo driven from a small air propeller. The voltage from this machine was most ingeniously

maintained at a constant value through a special application of the vacuum tube.

Such radio-telephone communication was of most vital assistance in the naval service. The battleships, cruisers, submarines, and the other naval craft could be engaged in conversation, orders given, information obtained and morale maintained through the medium of this radiotelephone service.

The radio system played a most vital part in the battle lines themselves. Both the wireless telegraph and telephone were in use as well as the regular wire communication. The giving of valuable information from one part of the front-line system to another, the transmission of orders in code, the learning of the location of the enemy lines and strongholds from the aeroplanes, which were the eyes of the army, all served in establishing a service efficiency that broke down the walls of imperialism.

The march of progress in the realms of wireless operation has not ceased, nor has there been a period of reaction so often the sequel of so intense a period of advance. New ideas are being born with each passing day and novel applications of the old principles cause the eyes of the world to stare in amazement. The direction by radio operation from a distant ground station of flocks of aeroplanes without operators in them, laden with most deadly explosives and ready to wreak vengeance on the cities of the enemy was an accomplishment completed at the very end of the war. These birds of death operated under the complete control of the hand on the key of the apparatus in the wireless station within the safety zone of a secluded spot well to rear of the lines. During the very month

that this paragraph is being written, it is the plan of the government to put into effect one of the most remarkable and unbelievable feats that the world has yet dreamed of. One of the great ocean greyhounds of the United States Navy will pull from her moorings and sail through the intricacies of the harbor without a human being aboard, being directed in her course by control of the operator in the little office room of the navy yard, as he radiates the pulses of æther disturbance which maneuvers the great propelling machinery and causes the vast dreadnought to respond in its action to the slightest desire of his mind.

Marconi has recently devised a new distress signal system that is the outgrowth of much study and experimentation in order that the ships at sea may be more securely safeguarded through the service of wireless telegraphy and telephony. The difficulty at the present state of the art lies in the fact that the operator must be constantly listening in to pick up any messages. At times when the operators are not on duty or are perhaps careless of their responsibility, a near-by ship in urgent distress may be signaling for help and yet its dangers may not be known. This new device that Marconi has perfected claims to send a succession of dots that will be so amplified by special detector devices that audible indication will attract immediate attention. As soon as the success of such a distress system has been assured, it should become a maritime regulation for each ship to be provided therewith.

Among the important applications of detection schemes there is one that has very recently been installed for the accurate guidance of ships into a harbor. Through the deepest sections of the Am-

brose channel, leading from the ocean into the heart of New York harbor, a distance of thirty miles, has been laid an electric cable. A current is caused to flow through this wire, which, you will remember, is always accompanied by a revolving field of magnetic lines of force about the wire. To each side of the incoming ship is attached a very sensitive detecting device, which is capable of registering the intensity of this magnetic field on either side of the vessel. Of course, if the vessel rides not exactly above this cable, but rather to one side, the detecting device on the near side of the ship to the cable would register a stronger deflection than the more distant side. Therefore, the pilot would be informed as to his relative position in respect to the middle of the channel. As the ship rides exactly over the middle of the cable, the field intensity in the vicinity of each detector would then be equal and the equal meter deflections would indicate this position to the pilot. The practicality and utility of such a device is most apparent.

RADIO THEORY FOR AMATEUR OPERATORS

The demand is incessant for reliable facts regarding the theoretical features of electric oscillating circuits such as are used in wireless telephony and telegraphy among the young enthusiasts who style themselves as amateurs. The interest of these young men should be properly directed and efforts made to assist them in mastering the important fundamental principles of the alternating current phenomena so that they may take a broader view of their work.

We must bear in mind that these boys of to-day are to take their places in the positions of responsi-

bility to-morrow. In the near future it will be they who shall direct the great wireless corporations, educate from the chairs of our technical institutions and prosecute research work that will render greater efficiency to the efforts of mankind. It is, therefore, important that at every opportunity contributions to aid these young and energetic minds should be placed at their disposal. With this worthy motive in mind, the following pages are added to this chapter on Radio Communication.

An oscillating circuit is composed of inductance and capacitance either in series or in parallel and is the all-important unit in radio frequency generation and reception. Since in this article only the production of radio frequency oscillations is considered, no further allusions will be made to the receiving phase of the subject. Since no electric circuit is wholly free from resistance, especially at the high frequencies employed in the radio field, the oscillations of electrical energy when once set up are diminished in amplitude, because of the dissipation caused by the joulean heating of the conductor system. This effect is called the decrement of the circuit, which increases with the ohmic resistance. In other words, the oscillations die out rapidly with a relatively high resistance and the system is said to be heavily damped. Such wave trains of damped oscillations are characteristic of a system energized by impulse excitation. Each impulse causes the production of an oscillating train of waves, the particular characteristics of which depend upon the nature of the oscillating circuit. The frequency of these oscillations is a function of the magnitude of the inductance and capacitance, whereas the damping of

the wave train is, for the most part, dependent upon the value of the circuit resistance.

The common method of producing impulse excitation for a radio oscillating circuit is by the use of a spark gap inserted in the circuit. As the voltage is built up across the gap and condenser, the associated electrostatic field acquires an increasingly greater amount of energy which becomes suddenly released when the gap resistance is broken down and the spark jumps, thereby reducing the voltage to almost nil. The energy of the condenser in causing the flow of the electric current through the inductance of the circuit establishes an increasing electromagnetic field. The decreasing energy of the electrostatic field is transferred to the increasing energy of the electromagnetic field, which interchange of energy relations continues until the heat dissipation of resistance has eventually damped out the oscillations. The number of wave trains produced per second will be the same as the number of impulses given to the circuit in that time by the sparking device. Mechanical vibrators of various types may give several thousand impulses per second, although synchronous spark gaps as generally employed on generator units give only a few hundred sparks per second.

The logarithmic decrement of a train of radio waves, as in any other system of oscillations, is the natural logarithm of the ratio of two successive maximum oscillations in the same direction.

This logarithmic decrement "d," expressed in terms of the three circuit constants, resistance "R," inductance "L," and capacity "C," is

$$d = \pi RC\frac{1}{\sqrt{LC}} = \pi R\sqrt{\frac{C}{L}}$$

The decrement of a wave train may be measured by several methods and is necessary among other requirements for the determination of the number of oscillations in a wave train. For a given initial and final amplitude of wave, the number of oscillations "n" is given by the relation

$$nd = \log \frac{I_o}{I_n}$$

where I_o is the initial current value and I_n is the current value of the n^{th} wave.

Although theoretically there are an infinite number of oscillations in a train, yet practically the wave train is complete when the oscillations are reduced to one per cent of the initial amplitude value. For example, the logarithm of $\frac{I_o}{I_n} = \frac{100}{1}$ is 4.6, hence for a decrement of 0.1 there are 46 oscillations in the train, while for a decrement of 0.5 only 9 oscillations constitute a wave train.

If there was no loss of energy in a circuit, there would be no decrement, and the electrical energy once started, oscillating would continue without diminution. The energy input into an oscillating system may be dissipated in the following ways:

First.—Heating the conducting system.

Second.—Heating the imperfect dielectric of the condenser system.

Third.—Producing electromagnetic waves called radiation.

Fourth.—If sufficiently high voltage is produced, an energy loss due to brush discharge or corona results.

These elements will be discussed more in detail in subsequent pages.

Thus far, only damped oscillations have been considered. They are not in general satisfactory for

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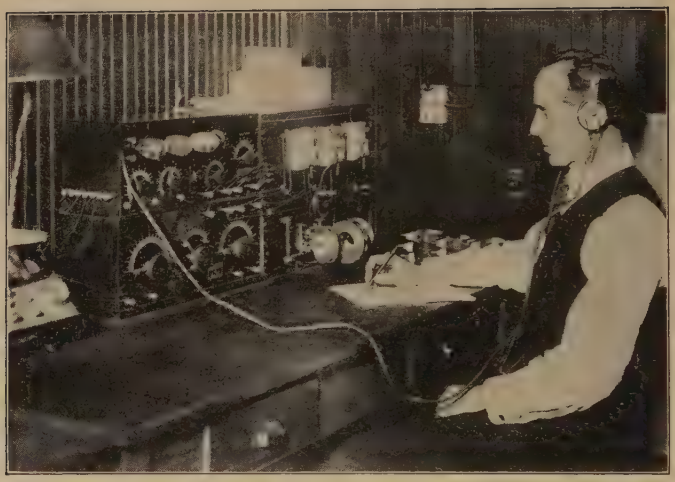
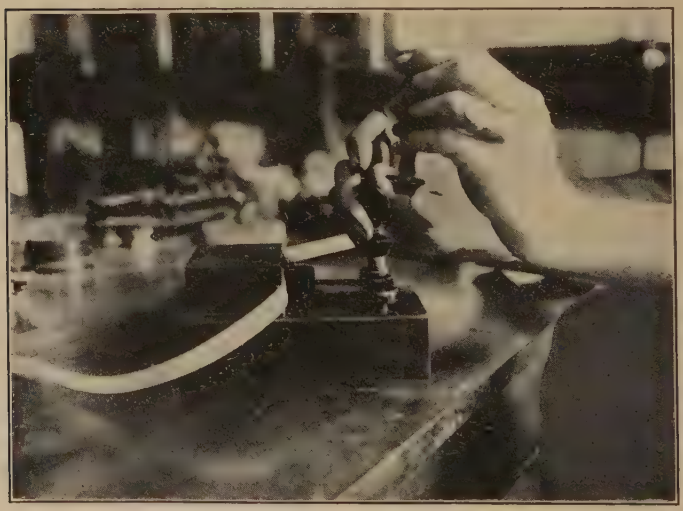
A GOVERNMENT WIRELESS STATION AT WASHINGTON, D. C.

This particular station, on the eighth floor of the Postoffice Department Building, is employed directing the air mail service and in sending out market reports to agriculturists.



TRAIN DISPATCHING BY WIRELESS

The picture shows an operating station of the Nashville, Chattanooga & St. Louis Railway.



AUTOMATIC TRANSMISSION TO SHIPS

The tape is being perforated in the Morse code. It will be passed through the automatic transmitter.

radio communication purposes. The undamped or sustained oscillations have almost wholly replaced the former in commercial work. It can be shown that the current

$$I = \frac{E}{\sqrt{R^2 + (wL - \frac{1}{wC})^2}},$$

is the current that oscillates in such a circuit. "E" is the voltage, "wL" is the inductance reactance, and "$\frac{1}{wC}$" is the capacity reactance.

This last relation is a basic equation of radio phenomena and an analysis of it discloses the facts concerning the subject of resonance. The above equation states that the current which flows in a circuit varies directly with the impressed E.M.F. and inversely with the circuit impedance. The E.M.F. being maintained constant, the current will increase to a maximum as "wL" becomes equal to "$\frac{1}{wC}$". The actual value of the maximum current in the case of resonance depends upon the value of "R" since the above equation then reduces to

$$I = \frac{E}{R}$$

This equation of the inductance and capacitance reactance

$$wL = \frac{1}{wC}$$

may be accomplished by variation in the frequency of the applied E.M.F. or by changing the value of "L" or of "C." The frequency at which reasonance occurs is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The smaller the value of resistance in the circuit the more sharp will be the condition of resonance and the greater the current value. This "sharpness of resonance" has a most important bearing on measurement of radio quantities. Obviously, the precision of the determination of frequency depends upon how sensitive is the current variation to changes in "L" or "C" at the resonant peak.

As previously stated, there are in general two classes of oscillation generators used in radio systems distinguished by the type of waves emitted. The first and oldest class which produces the damped oscillations, uses an alternating current generator in conjunction with a spark gap usually of the synchronously rotating type. The alternator impresses its voltage upon a step-up transformer of high transformation ratio. This high potential difference is then impressed upon the oscillating circuit composed of a condenser of Leyden jars or other forms of high voltage condenser units, an inductance coil of a few turns of heavy conductor and the synchronous spark gap all connected in series. The antenna system in this case is usually connected by an inductive coupling to the oscillating circuit.

The second class of generator produces undamped or sustained oscillations which system has become most popular by virtue of its superior characteristics. There are three distinct types of such generators which may be designated as follows: (1) high frequency alternators; (2) oscillating arc generators; and (3) thermionic valve or vacuum tube generators.

Of the first type the Alexanderson alternator—an inductor type of alternator—has become most extensively used in this country for high power long-

distance transmission. Its E.M.F. is generated at a sufficiently high frequency—50,000 cycles—to be impressed directly upon the antenna. They are built in sizes capable of delivering as high as 200 K.W. of power.

The second type, known as the arc generator, makes use of the sensitive resistance variation of an electric arc to cause the resultant rapid E.M.F. variations to force an oscillating circuit into action. The most notable of this particular type is the Poulsen arc generator which has been built in sizes up to 1,000 K.W. They are in higher favor among the radio engineers of Europe than in this country—although a few large power installations are being utilized in America.

The third type of undamped oscillation generators known as the vacuum tube type is employed in the plants of smaller size. These tubes for generation purposes have been made as large as 5 K.W. Such tubes are known as "3-element" tubes, having a heated filament, a plate and a grid system. The heated filament radiates electrons, which are directed to the plate by virtue of a directive potential difference existing between the filament and the plate. The interposition of the grid in the path of the electron flow may regulate this flow in most minute degrees by variations in the grid potential. There are many wiring circuits for different connections of the three elements to the oscillating circuit for generator purposes. The antenna may be inductively coupled to the oscillating circuit or directly coupled, that is, by autotransformer coupling.

The determination of the frequency of oscillation or conversely of the wave length of the radiation is

of the utmost importance. This is accomplished by means of the wave-meter, one of the most indispensable devices in radio measurements. A laboratory wave-meter is comprised of a *radio standard of inductance, a standard variable condenser,* and a *sensitive thermo-galvanometer,* connected by *heavy leads* to form a series circuit. A single or even half loop is made in the conductors of the system whose wave length is to be measured. The wave-meter is set up at a considerable distance, very loosely coupled, with the plane of the inductance coil about parallel with the plane of the loop. By varying the wave-meter capacity, a value will be obtained where a maximum reading on the galvanometer is noted. This point being the point of resonance of the wave-meter indicates that the feeble current in it is oscillating at the same frequency as the circuit under measurement. The frequency of the current in the wave-meter circuit can be calculated from the meter constants and, therefore, the wave length of the oscillations may be determined. The wave-length is obtained by dividing into the distance traversed by electromagnetic waves in one second the frequency of the oscillations. Or

$$\lambda_m = \frac{2.998 \times 10^8}{f} \text{ (wave-length in meters)}$$

multiplying by 2π in both numerator and denominator gives

$$\lambda_m = \frac{1.884 \times 10^9}{w}$$

since $$w = \frac{1}{\sqrt{L\,C}}$$

$$\lambda_m = 1.884 \times 10^9 \times \sqrt{L\,C}$$

where L = henrys of inductance
C = farads of capacitance

$$\lambda_m = \frac{1{,}884{,}000}{31.6}\sqrt{L\,C} = 59{,}600\sqrt{L\,C}$$

where L = millihenrys of inductance
C = microfarads of capacitance

A very common and practical form for this last equation is obtained by expressing "L" in millihenrys and "C" in micro-microfarads as follows:

(A)
$$\lambda_m = 59.6\sqrt{L\,C}$$

The resistance of a wave-meter circuit should be very low in order that the point of resonance be most sharp. The slightest variation of the capacitance either way should be noticeable in reducing the magnitude of the galvanometer deflection. This affords an excellent example of the importance of the sharpness of resonance. On the other hand, an oscillating circuit may be tuned to the wave-meter when a definite wave length is desired. The condenser of the wave-meter may be set to the wave length desired as computed from equation (A) above. The frequency of the oscillating circuit is then varied, until the galvanometer of the wave-meter indicates a maximum deflection. The circuit is then oscillating at a wave length as indicated by the wave-meter.

To further illustrate the importance of the wave-meter in radio measurements, consider its use as a calibrating device for inductance and capacity units. To calibrate, that is determine the correct value of a condenser, one may proceed as follows: Adjust the generator to oscillate for the wave-length set by the standard wave-meter. Then replace the standard condenser by the one under calibration and vary its capacitance until resonance is obtained. The

capacity may be then computed by equation (A), "λm" and "L" being known. Repeat this process for enough points to establish a reliable calibration curve. To measure an unknown inductance, the same general substitution method may be used where the unknown inductance may replace at a known wave-length the standard inductance. Tune to resonance by varying the capacitance, from which value the unknown inductance may be found, since the wave-length and capacitance are known.

A standard wave-meter becomes very useful at times as a standard frequency generator when a small, clear-toned buzzer is connected into its circuit to give impulse excitation. Such a system is desirable for the calibration of other wave-meters. The current in the wave-meter under test may be too feeble to record on a galvanometer and the use of a crystal detector with accessory phones is recommended in this case, employing a unilateral connection to the wave-meter—that is, a connection at one point.

The wave-meter is particularly convenient as a means for the simultaneous measurement of the inductance and capacitance of an oscillating system such as an antenna circuit. The wave-meter is tuned to the frequency of the antenna. The wave-length of the antenna then becomes known and the equation representing this relation is

(B)
$$\lambda_a = 59.6\sqrt{L_a \cdot C_a}$$

where L_a = the unknown aerial inductance
C_a = the unknown aerial capacitance
λ_a = the known wave-length in meters

Then insert in series with the aerial, either an inductance coil of known value "l" or preferably a

condenser of known value "c." The wave length is again determined. The equation then becomes when the inductance is used

(C) $$\lambda_a^1 = 59.6\sqrt{(L_a + l) \cdot C_a}$$

Equations (B) and (C) then form a pair of simultaneous equations with two unknowns, "L_a" and "C_a" which values may be determined from solution. Since the inductance coil has some distributed capacity, the above method is not free from a small degree of error. If, however, a known condenser is inserted in the antenna circuit, the remeasurement will have a higher degree of precision because the condenser has practically no inductance. The equation would in that case be

(D) $$\lambda_a^1 = 59.6\sqrt{(L_a \cdot \frac{C_a \cdot c}{C_a + c}}$$

which may be likewise solved simultaneously with equation (B) for "L_a" and "C_a."

One general source of error should always be guarded against in precision measurement where the capacity is so extremely small, namely: the fictitious capacitance due to the unused end turns of a variable inductance coil. This fictitious value affects the wave-length, but does not enter into pertinent computations and is not even constant when various settings of the inductance coil are made. To insure against such errors in wave-meter circuits, they are made with variable capacity units rather than variable inductance coils.

There are in practice many types of antennæ, all of which are used because certain inherent characteristics peculiar to each adapt them for particular

classes of work. The two most common forms in small stations are the "T" and the "L" types. The "flat" section of the aerial is made of several wires held uniformly spaced by stays and thoroughly insulated. These wires are joined in parallel at either end where insulators support them from the masts. If the "lead-in" wires connect to the aerial at either end, thereby forming an inverted "L," then it is called the "L" type. In the case of the "lead-in" wires connecting to the middle of the horizontal section, the antenna is called the "T" type. The inductance of the "T" type is very much lower than the "L" type antenna, due to the fact that as the current passes from the "lead-in" wires through the junction to the flat part of the aerial, two equal divisions of current flow away from the junction point, the inductances of which branches neutralize and render the total inductance a minimum.

All conductors for radio frequency currents should be stranded cable with a relatively large number of untinned insulated strands so that the skin effect or nonuniform distribution of current over the conductor cross section will be reduced to a minimum. If the strands are tinned, the outer shell of each strand having a higher resistance metal will cause the effective resistance to greatly increase.

The distributed nature of the inductance and capacitance of an antenna system together with the many associated variables prohibit any accuracy in the calculations applied to antenna characteristics. Equations for the calculation of the antenna inductance, capacitance, and resistance serve at best as mere rough approximations. The capacity effect may be relatively large in antennæ of large aerial spread, whereas in certain of these types the in-

ductance may be inherently a minimum. The current at the point where the antenna voltage is zero, that is near the ground, is called the *antinodal current.* In other words, the *antinodal current* is the full input value before any dissipation into the distributed capacity occurs. This current value should always be used for calculation purposes.

As previously stated, the energy required to maintain oscillations in an antenna system is dissipated in three ways: (1) radiation; (2) heat, due to conductor resistance; and (3) heat due to imperfect dielectric characteristics. Of these three types of energy dissipation, only the first represents useful functioning, being used for the production of the electromagnetic waves employed for signal transmission. Good radio design dictates relatively small losses due to the latter two items, namely: conductor and dielectric heating. The ohmic heating is caused by not only the normal resistance of the antenna wires, but also by earth resistance, skin effect, and eddy currents in the wires and ground. The changes in this resistance are so small, however, compared with the other variations that this element may be considered constant or free from variation due to wave-length and current density. The power consumed by this ohmic resistance component is equal to the product of the resistance and the square of the antinodal antenna current. This power loss is reduced by the use of copper cable of ample cross section for the aerial system and by the establishment of a good ground. The power loss due to the imperfection of the condenser dielectric depends materially upon the nature and position of these dielectric substances relative to the antenna field. Buildings, trees, and various incumbrances

under an antenna increase to a marked extent the dissipation of energy. Since this dielectric loss is a heat loss, it can be expressed as the square of the antinodal antenna current and a resistance. As this loss increases directly with wave-length, obviously the resistance is a direct function of the wave-length. To most economically conserve the energy of an oscillating antenna system, clear the environment from any deleterious influence.

The radiation dissipation should be relatively large: but this depends upon several factors among which are: (1) antenna form; (2) square of the antinodal antenna current; and (3) inverse value of the square of the wave-length of oscillation. This power loss, therefore, being proportional to the square of the antenna current, could be considered due to a resistance which has been called radiation resistance. This radiation resistance is inversely proportional to the square of the wave-length of oscillation. If through such a radiation resistance a current equal to the antinodal current is passed, an amount of power will be dissipated equal to that radiated from the antenna.

The addition of these *three effective resistances* gives the *total effective antenna resistance.* It is a resistance whose value changes with a function of wave-length and may be defined as that resistance which if placed in the antenna at the current antinode would dissipate the same energy as that of the antenna. Its value increases rapidly for short wave-lengths.

CHAPTER XIII

ELECTROCHEMICAL APPLICATIONS

THE world at large accepts the comforts and luxuries that are introduced into it with a grace and ease which is really remarkable. Little do we question the origin of such creations. Profound thought is seldom ever given to the processes of the manufacture and the degree of industrial attainment requisite to their final perfection. For example, consider for a moment the universal application of the automobile for business and for pleasure. Do we ever pause to ask ourselves by what process the steel of our gasoline engine is made or how the polished smoothness of the engine crank pin is produced, or how the calcium carbide of the old acetylene lamps was manufactured and how the nickel plating of the machine trimmings was accomplished?

We pay no tribute to the pioneers in the many essential branches of industry; not even do their names enter into the discussion of the home circle. Probably only one out of each hundred of the readers has ever heard of the man whose work is most closely associated with the subject matter of this chapter. Perhaps the average reader may even set his mind against the content of such a chapter, with the excuse that although he recognizes and appreciates the applications of electricity, he yet sees little in the chemical processes involved. Little

does such a reader know of the human relationships represented. As he reads this print by the light of a Tungsten lamp he is indebted to the genius of a brillant man for the preparation of the tungsten metal. As he walks with safety down the street in the evening under the protection of the artificial illumination of some powerful arc lamps, he is again unknowingly within the indebtedness of this same man for the manufacture of the carbon electrodes. Again, the brilliancy of the beautifully cut diamond that rests in a ring is a further accomplishment of the ability of the above genius who devised the method of accurately forming the geometrical fasces of the precious stone. As one glides with noiseless speed through the beautiful country in one's automobile, it is but seldom that we consider the part played by *lubrication* of the differential or of the springs. The distraction caused by ceaseless squeaking and warning noises from the friction of the parts, however, cause one to admire the genius who invented the lubricant that removed these undesirable elements. Again we are unknowingly appreciative of the work of our above "man of the hour."

We are greatly indebted to one man's ability, endeavor, and achievement for the above-mentioned comforts and for many more of great importance either directly or indirectly. This man is Doctor Edward G. Acheson. He is "discoverer and maker of carborundum, the world's greatest abrasive; inventor and manufacturer of oildag, now coming to be recognized as the world's greatest lubricant, creator and producer of the only artificial graphite ever given to the world; originator of metallic silicon, which has brought the price of that indispensable

commodity down from $2500.00 to a few cents a pound; maker of a new form of ink, which promises figuratively as well as literally to write industrial history." These commodities which have become fixtures in the constellation of industrial manufacture, have been realized through the successful application of electrochemistry. Doctor Acheson early conceived the use of electricity in producing the tremendously high temperatures needed for making certain types of chemical reactions. To accomplish the ends desired he constructed the electric furnace, which now has most extensive application in making the highest quality steel, carborundum, artificial diamonds, and many products of carbon.

The broad field of industrial electrochemistry may be divided into three distinct classes as follows: (1) electric furnace processes; (2) electrolytic processes; and (3) processes that involve electric discharge through gases. The field of electrolytic chemistry is most productive in wealth. Among the applications in this industrial pursuit may be mentioned; refining of metals such as gold, silver, copper, etc.; electrotyping; and electroplating.

One of the most recent fields of discovery is that involving the discharge of electricity through gases in which the formation of ozone is an important one. The fixation of nitrogen from the atmosphere has attracted world-wide and popular interest, since the nitrogen compounds, so essential to fertilizers and the manufacture of explosives, are available from nature in such limited quantities as to threaten a serious shortage thereof. The methods of dust and smoke precipitation, too, are growing in demand and application may well

receive consideration under the head of electrochemistry.

In the following pages some of the methods of industrial applications for making the commodities which are so fundamentally involved in general manufacture will be considered, and the products themselves will be given special attention.

ELECTRIC FURNACES

Electric furnaces were first devised in order to carry into effect certain types of reactions of a chemical nature involving the use of very high temperatures. Electric furnaces have the two advantages of first operating at temperatures higher than any obtainable through other processes; and second, permitting easy control of temperature and of the atmosphere within the furnace. The one factor which influences the use of the furnace is the cost of electric energy. The high rate of charge for electricity in many localities precludes the use of electric furnaces. In many places, however, where hydroelectric power is obtainable at very low charge, the electric furnace industry has prospered. For that very reason the low rate for power at Niagara Falls has attracted the industrial plants, which operate in great numbers in the vicinity.

The maximum temperature to which electric furnaces may be operated in practice is about 3,500 degrees Centigrade, or about 6,300 degrees in the common Fahrenheit system. Such a high temperature is capable of melting almost any substance known with the exception of certain forms of carbon. The temperature may be most conveniently and readily controlled, since the flow of current may be regulated according to the specifications of

Ohm's law. During certain types of electrochemical reactions that are carried into execution by the furnace, both the temperature and the atmosphere that exists in the furnace may be controlled to meet the needs of any demand.

The electrical energy may be changed into heat by either of the following methods: (1) by producing an electric arc in which the heat is evolved from the arc itself; and (2) by forcing the electricity through the resistance of the furnace, in which case the heat produced depends upon the product of the ohms of resistance and the square of the current in amperes. In many furnaces, however, the heat is produced by a combination of the arc and the resistance effects. The two above methods of heat production suggest the two types of furnaces, one called the *arc type* and the other the *resistance type.*

The arc type of electric furnace may be of two general types, depending upon whether the heat of the arc plays directly upon the substances under treatment, or whether the heat of the arc is principally reflected from highly polished surfaces to the material under the action. The former type uses *direct heating* and the second the *reflection heating.* Figure 206 shows a Moissan arc furnace where the electrodes, the heating crucible and the heat insulation media are shown. Some of the indirect types of arc furnaces have a revolving retort where the charge is constantly and thoroughly mixed. Such action may be essential to certain types of charge and for such work would be highly recommended.

The resistance type of furnace is further subdivided into two subtypes, depending upon the con-

stituents of the resistance elements. The heat may be produced from a resistor element which is a part of the electric circuit and is used for that purpose only, or again the charge of the furnace may constitute the heating element of the furnace. This latter method may be used where the charge is a fairly good conductor of electricity. In some cases, such as steel and iron purification, the element for the heating is the charge and all the heat generated

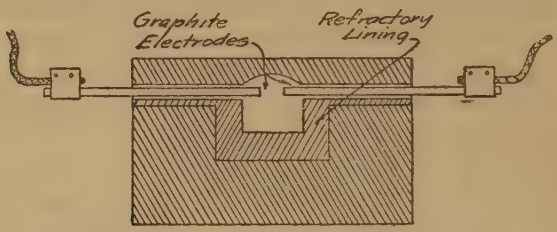


FIG. 206.—MOISSAN TYPE OF ELECTRIC ARC FURNACE

is effective in producing the desired result. In the case of the carborundum furnace the charge is not a good conductor of the electrical energy, and in order that the reactions take place in the presence of great heat, a special resistor unit must be employed to serve the desired end. Many times no sharp line separates these two types. In some of the Acheson products, such as the manufacture of bulk graphite and graphite electrodes, the charge as well as the electrodes serve to conduct the electricity and to generate the heat.

There is, however, one other type of furnace that has met with success, known as the *induction type electric furnace*. It uses alternating current, rather than direct current and in reality is a transformer of which the secondary is a single turn and

constitutes the inner chamber or part of the retort. The electrical energy is in this case transmitted by the electromagnetic induction. Such a furnace is used for work in steel and iron plants for melting-up processes and conversion to high-grade materials.

One distinct advantage of such a type of electric furnace lies in the fact that since there are no inner electrodes, the charge may be affected in no way whatever by the presence of electrode contamination. In this way, therefore, the composition of the output may be closely controlled by suitable selection of the input raw materials. A further advantage of such a furnace is its ability rapidly to heat and get under way with its action.

DIRECT CURRENT VERSUS ALTERNATING CURRENT FOR USE IN ELECTRIC FURNACES

The alternating current application in electric furnace operation has two advantages over that of direct current. One effect is the exclusion of any undesirable electrolytic action. Since the current flow is constantly reversing, any action that is started in one direction is reacted in the other direction to restore chemical equilibrium. This is not always true, but depends upon the type of substances which are submitted to such action. If the action and reaction are reversible, then such a restoration as above described is true. In the majority of cases, however, such a phenomenon is true. The second advantage of alternating current over direct current lies in the facility of control over the energy flow. The voltage of a transformer may be readily varied on the secondary side by means of end taps to the coil or by the use of an auto transformer. With direct current, regulation

of the current may be affected in general by the inserting of a resistance in the line, but this produces a great loss. Where a motor generator set is used for the production of direct current when alternating current is supplied, good control may be secured from the field regulation of the generator. Since the motor generator set, however, is not more than 80 to 85 per cent efficient at best, a considerable loss of energy therein results.

FURNACE LININGS OR REFRACTORIES

The proper construction of refractories and of furnaces is of the utmost importance if they are intended to produce materials of high-grade quality. The inside surfaces of the furnace retort is exposed to tremendous heat and it must, therefore, be so made that it will not melt and thereby affect the charge of the furnace. The material of these walls also must be of such a substance that any action within the lining itself will not enter into the chemical actions of the charge.

In connection with the subject of the chemical effects of refractories upon the furnace charges undergoing their heat processes, it will be convenient to classify refractories as follows: (1) acid refractories; (2) neutral refractories and (3) basic refractories. The refractories employed must in all cases be chosen to suit the constituents of the respective furnace charges, in order that no interaction may be promoted and thereby ruin the entire product. For example, if a *basic charge* is being used in the furnace, the linings must not be of an *acid type*. *Neutral refractories* are so called because they do not take part in the action of the furnace charge in any particular.

Silica is the chief constituent of *acid refractories. Fire clay, chromite,* and *carbon* are those of *neutral refractories. Basic refractories* are *lime, magnesia, bauxite,* and *dolomite.* Success with furnace work depends largely upon the knowledge of the fundamental principles regarding actions and reactions between the elements of the furnace construction and of the charge which constitutes the raw materials of the final product. The school of experience rather than theory has so far guided the formation of certain lines of progress and pursuit in this industry.

Briefly stated, the primary characteristics that refractories should have are as follows: (1) They should withstand high temperatures; (2) they should resist chemical effects upon the furnace charges; and (3) they should have high heat insulation value. The first and second of these characteristics have already been considered. Before leaving this part of the subject, however, an explanation will be given of the third point. The reader may remember that in several different places in previous chapters it was stated that a bad feature about the insulation used for electrical work was that in many cases this insulation proved to be a good nonconductor of heat. This is indeed a very unfortunate circumstance, because the heat being generated directly within the wire and its insulation, is prohibited from escape by the heat insulating characteristic of these insulations. This results in a rise of temperature greater than would otherwise be the case. Refractories, however, must have a high heat insulation value in addition to being merely physically capable of resisting the tremendously high temperature of the furnace. This

quality of high heat insulation is most desirable, because the ultimate temperature obtained in such a furnace depends fundamentally upon the insulation of the walls against the escape of the heat. Furthermore, since the heat comes from conversion of electrical energy, conducting walls would mean a high electrical energy expenditure at a high cost of operation. Fortunately, the materials that best withstand the high temperatures do insulate the flow of heat in a fair degree.

Carborundum is one of the best refractories for general use. For substances that are made under temperatures less than that which affects the carborundum, a wall of lining made thereof would give excellent and prolonged service. In some industrial products such excessive temperatures are required that even this refractory carborundum will not suffice. In this event *carbon* in the form of *charcoal* has the highest resistance to heat of any known material.

PRODUCTION OF GRAPHITE

One of the very extensively used products of mother earth as well as of industrial manufacture is *graphite*. It is used in tremendous quantities. The lead of pencils, the basis of paints and pigments, the most efficient of all lubricants, the body of stove polish, the brushes of all electrical machines, the electrodes of arc lamps, the elements of certain batteries and cells are all the products of graphite. The earth contains graphite in a limited amount and, therefore, there has been a danger of the supply giving out sooner or later, as is true of many other natural resources. The future supply of graphite, however, has been per-

manently assured by the industrial manufacture of it in any bulk desired.

In all probability within a few years graphite as a lubricant will find universal application to the exclusion of practically all other lubricants. "Realizing how much depends on transportation, and how much in turn, transportation depends upon lubrication, many thoughtful authorities are extremely alarmed over the utterly reckless manner in which this country is using up its supplies of petroleum. Some geologists estimate that, at the present rate of consumption, our oil resources will be exhausted in twenty years; and no authority of high standing figures that they will last more than a generation at the most." Such statements from authorities in their lines often bring us up to an abrupt halt and cause us to wonder what the result will be. We soon cast aside any fears we may have, however, by saying that we will be dead and buried long before such a condition takes place.

The genius of brilliant minds will create some substitute either as good or better than the original.

Artificial graphite, one of these substitutes, is made by the Acheson process. There are three general classes: (1) hard graphite for paints, etc.; (2) graphite electrodes for electric furnaces and electrolytic work; (3) soft graphite for use as lubricants, etc.

CARBORUNDUM

As already stated carborundum has become the world's greatest abrasive. It is one of the hardest materials known and is used to polish and cut the diamond from the rough to the finished product. It was the outcome of experiment and careful analysis by Doctor Acheson. Many years ago as he

was experimenting with mixtures of clay and carbon fused in the retorts of the electric furnace, he discovered small shiny specks with which he could scratch glass and even diamonds. At last the result of his long years of dreams about an abrasive suitable for the requirements of diamond cutting was realized. The first product was sold at the rate of $800.00 per pound.

This discovery proved to be the making of Doctor Acheson, since the demand for his product so far exceeded the supply that the baby industry was overwhelmed. Demands arose rapidly for it in Europe as well as in America, and innumerable prize awards were made to honor the skill and name of the inventor.

Strange enough to relate, it was not until after the discovery of the method of producing carborundum had been found, that it was learned that carborundum existed in the universe in a natural state. It has not as yet been found in this globe of ours; but in Arizona a speck of carborundum was found in a meteor which had fallen from the infinitudes of space. A French scientist in analyzing the constituents of the meteor struck upon some particles which stripped saw blade after saw blade from his hack saw as he attempted to complete his work. Analysis of the components of these specks revealed the astonishing results that it and the artificial product of Acheson were exactly identical. Doctor Acheson once remarked that he was beginning to believe that there is nothing in nature that man cannot reproduce except the elements and the breath of life.

Carborundum is the trade name given to the chemical product known as *silicon carbide*. It is

made of a charge of carbon, sand, and salt in the electric furnace. When such a mass is heated into a molten state where chemical affinity forms the proper action and reaction and then allowed to cool, the cooling, of course, takes place on the surface layers first, which, by the laws of nature, we know contract. This contraction of the outer layer creates a pressure within of tremendous value which probably has something to do with the formations that occur. Tiny diamonds have been artificially made in this way that were fully as perfect as those of nature. Not only is carborundum the very best abrasive known, but it is also a fine refractory for furnace linings.

OTHER INDUSTRIAL APPLICATIONS OF THE ELECTRIC FURNACE

The most excessive heat of such electric furnaces has been effective in melting or smelting quartz into fused quartz vessels of any desired shape. Such vessels are extensively used in chemical laboratories in certain types of electrical equipment, such as the *ultra-violet ray tube, water sterilizers,* and so forth. The process is also applied to vessels, beakers, etc., which are to be used where temperature variations will vary within wide limits, and where all danger from cracking is desired. Through experience we are well aware that to pour boiling hot water into a cold glass jar or other container is followed with the disaster of a cracked and broken vessel. This breaking is accomplished through the enormous strains of expansion of parts of the vessel and in unequal degrees. A characteristic of fused quartz which obviates this danger results from the fact that the

expansion is practically zero for variations in temperature.

Calcium carbide is a product of manufacture of the electric furnace of most important consequence. It is used chiefly in great quantities for acetylene lighting. The acetylene gas is formed when the calcium carbide comes into contact with water. The furnace charge from which the above product is made consists of burnt lime and ground coke.

One of the very important applications of the electric furnace is found in the steel industry. It is employed in the super refinement of steel by the open hearth and Bessemer processes. The electric furnace method of manufacturing high grade steel is giving keen competition at present to the crucible process. It is a cheaper method since the expense of the pure and costly starting material necessary for the crucible process need not be employed in the electric furnace method. Further reduction in cost lies in the employment of large units and less cost of labor. High quality rail steel, which has heretofore been made solely by the Bessemer and the open hearth processes is now being produced in a constantly greater amount with the electric furnace method. The production of pig iron by the electric furnace process is meeting with increasing favor as its extension in the industry grows.

ELECTROLYTIC PROCESSES

The processes involved in the industrial manufacture of many of our most important commodities are accomplished through the electrolytic methods. The manufacture of many of the caustics, the refinement of metals, electroplating and electrotyping are all phases of this great art.

The galvanic cell or battery has already been described as a device by means of which electromotive force may be produced and electric energy caused to flow. That is, the galvanic cell is a source of electrical energy. In the electrolytic methods, the electrolytic cell is virtually the reverse of the galvanic type. There is also a cell which contains the electrolyte and a system of electrodes, through which an electric current may be forced and made to produce reactions at the electrodes of the reverse nature to those of a galvanic cell.

Electrotyping constitutes an art of great importance in the world of printing. The reproduction of set-up type, of engravings, of medals, and of other devices may be accomplished through the medium of *electrotyping*. Perhaps you wonder just what is meant by electrotyping and how it is accomplished. A mold is made of the print and characters to be reproduced in a surface of wax or other similar substance by impression under great force. This tablet of wax impression is now painted with some electrical conducting material, such as graphite, to render the surface a conducting medium. The wax tablet is then placed in a plating bath of copper made of a ten per cent sulphuric acid solution saturated with copper sulphate (blue vitriol) salts. A wire is attached to the wax surface containing the impression and this plate is made the cathode of the plating vat. As the electricity is now forced through the cell, the copper of the solution or electrolyte is caused to be carried to the wax plate deposited thereon. The deposit grows in weight in exact proportion to the strength of the current that flows and to the time that the current flows, that is, to the ampere hours. After

a sufficient deposit has been made, the action may be stopped and the copper-plated wax impression removed. The copper plate may then be separated from the wax backing. This plate, however, is very flimsy and may be readily damaged because of its frailty. In order to give it strength it is backed up with molten type metal which, when hard, makes it sufficiently strong. In this form it may be mounted in the printing machines for use as desired. Steel engravings may in this way be copied to any desired number. This is illustrated in the Government Printing Bureau in Washington, where several hundred stamp prints for printing sheets of postage stamps are assembled into one great plate. Likewise, in other forms of printing where great numbers of prints are essential, this method may be used effectively.

ELECTROPLATING

One of the large and prosperous industries that this country fosters is that of *electroplating*. Practically all of the many forms of plating are now accomplished by electrical processes. In one case it is the plating of some base metal with the rare and costly metals, such as gold or silver. In other cases the plating is for purposes of preventing any corrosion effect upon surfaces that are desired to be bright. Nickel-plating admirably serves such purposes and is most extensively used for such work. Copper-plating has many usages in electrical work in order to render greater conductivity to basic metals that are stronger. Copper-coated iron and steel wire are used for telephoning and telegraphy systems for long lines. The plating process may be continued as long as desired and will pro-

duce a coating of copper the thickness of which will increase as the product of the time and current increases. That is, one ampere of current will deposit a definite amount of copper or other metal in a minute. Two amperes will deposit just twice as much. Furthermore, in two minutes one ampere will deposit just two times the metal that would be deposited in one minute of time.

In such electroplating processes the object to be plated is made the cathode plate, whereas the electrolyte or solution is made of a concentrated solution of the metal to be deposited. The anode or other plate may be composed of the same material that is deposited or it may be inert, in which case it does not affect the reactions in any way. The solution should always be saturated—that is, contain as much as possible of the mineral with the metal to be used in plating.

In the case of electroplating, a small current is usually employed and a voltage from one to six volts is all that is necessary. As the current is forced through the electroplating vat from the anode through the electrolyte to the object to be plated, particles of the metal called *ions* are carried to the cathode and there deposited. Where the anode is a plate of metal of the same material as it is desired to deposit, as much of the metal by exact weight as deposits upon the cathode goes into solution at the anode, and the quality of the electrolyte remains unchanged. Where an inert electrode is employed as the anode, the electrolyte must be maintained in its saturated state by the addition of the proper crystals of the metallic salt.

Where many small objects are to be electroplated, it is desirable to have these articles in constant

motion, such as a rotation, so that by continual change of the position of the articles the plating will be even and uniformly applied. Of course, in commercial plating it is desirable to accomplish the plating in the shortest possible time in order that the vats may be put to the most extensive use. If the time element is short for a certain weight of plating, the current density must be correspondingly high. Unfortunately, there is a limit to the density of current that is allowable. As the current density approaches a certain value, there occurs at the cathode a dilution of the electrolyte of the metal ions and a danger of some other element forming part of the plating results, in which case, the resultant plating, if not entirely ruined, would certainly not be desirable.

In order that the deposited metals should adhere firmly to the surfaces plated, they must be thoroughly cleaned both mechanically and chemically. The presence of any fats or oils would cause serious difficulties. Some of the solutions that are used in commercial plating will be given below together with any necessary precautions, since many times the young reader with experimental tendencies finds great pleasure in such play and by all means should be encouraged to work along educational lines. It is quite safe to say that nickel-plating is most extensively employed.

NICKEL-PLATING

The solution employed for the electrolyte most commonly used is made by dissolving twelve to fourteen ounces of nickel ammonium sulphate in one gallon of water placed in a new stone crock and boiled. Then water is added until a hydrometer

registers about 7 degrees Beaumé. The solution should be only slightly acid, since it has been found that too great acidity causes peeling off of the plating while alkilinity causes the color of the deposit to be darkened. Boracic acid has been found to be a desirable addition to improve the tone of the work. A current density of from 0.05 to 0.10 amperes per square inch of the object to be plated has been found to be about as much as can be successfully used. With the above solution as an electrolyte use a nickel plate for the anode which is at least larger than the surface to be plated. Cast nickel is better than the rolled nickel plate.

A part of this subject of plating of no little importance is that which deals with the treatment of a metal surface before it can be finally plated as desired. Some materials may be directly plated with the desired metal, whereas other metals, as basic substances, will not take the plating metal without preparation. For example, iron will not directly take a nickel-plating, but should be first prepared by giving it a copper-plating. The presence of iron in the electrolyte of a nickel-plating solution will impair the perfection of the result.

OPPER-PLATING

The electrolyte which has given in general the best commercial results is called the *cyanide solution.* This is made as follows: to each gallon of water add five ounces of copper carbonate, two ounces of potassium carbonate; and ten ounces of pure potassium cyanide. Dissolve separately each of the above constituents in water. Add to the potassium cyanide solution the copper carbonate

solution. To this composite solution add the potassium carbonate solution. The density should be adjusted to 100 degrees Baumé, and the electrolyte should be ready for use. It is desirable, however, first to test out for results before submitting the entire work to the bath. Copper or cyanide or both may be added as experimentation dictates until satisfactory results are obtained. About 0.02 ampere of current per square inch of surface to be plated should be used. The anode should be made of pure metallic copper preferably in sheet form about the cathode.

SILVER-PLATING

One standard formula for the electrolyte for silver plating is given as follows: dissolve twenty-five grams of pure silver cyanide in a solution of twenty-five grams of potassium cyanide in 300 to 500 grams of water. Then dilute the solution to make one liter. The current density that is recommended is from 0.0025 to 0.010 ampere per square inch. Of course, it applies in all types of plating that the objects to be plated should be thoroughly clean and free from oil and fats. Best results are obtained also when the anode has a large surface and more or less completely surrounds the articles to be plated.

An important process of industry is the zinc plating of iron as a protection against rust. This process is called *galvanizing*. One way is to dip the iron into a solution which adheres and is called the *cold galvanizing*. There is also an electroplating method of depositing the metal on the iron which gives far greater service and is much more desirable. Such electrolytic process gives a denser, tougher, more uniform and more resistant deposit

than by any dipping process. To further illustrate the importance of properly preparing the surfaces of a metal for a certain plating, consider the gold plating of aluminum. First, the aluminum must be zinc-plated since this adheres best to the aluminum, a metal most difficult to plate. The gold cannot be then plated over the zinc because experience has taught that the gold will soon be dissolved and, therefore, disappear. The zinc-plating should first have a coating of copper after which the gold deposit may be made with no further difficulty.

ELECTROLYTIC REFINEMENT OF METALS

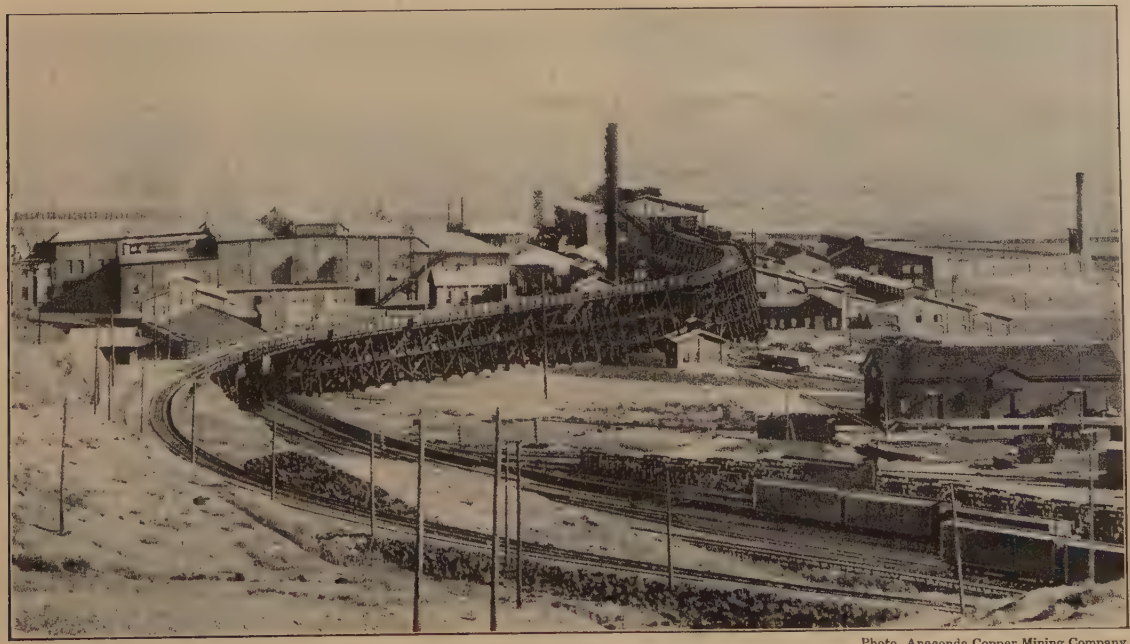
The production of absolutely pure metals from high-grade alloy is a most important function of electrolytic processes. The product of the ore refinements, where vast quantities are run through, gives an alloy that is highly concentrated with the desired metal. The impurities, however, may and often are of the valuable metals such as gold and silver. In order to refine the fundamental metal and at the same time as a by-product salvage the precious metals, no method gives the satisfaction and the ease that does the electrolytic method. The copper refining industry in this country takes an alloy of 98 to 99 per cent and gives 100 per cent pure product. The statistics in regard to copper refinement for one year are as follows: During the electrolytic refinement of 279,000 tons of copper, the by-product of precious metals that were recovered was 27,000,000 ounces of silver and 346,020 ounces of gold.

The anodes of the great refining vats are composed of the impure metal to be refined. The electrolyte is composed of a thirteen per cent solution

of sulphuric acid and a three per cent quantity of the copper in the copper sulphate salts. A little salt addition is an advantageous adjunct since it assists in precipitation of silver, antimony, and chlorine gas. As a current ranging from twelve to thirty-five amperes per square foot of surface is passed through the refining vats, the pure copper is carried over on to the cathode, whereas the impurities such as gold, silver, zinc, antimony, and arsenic are either dissolved and held in solution or are precipitated. The cathode copper is pure to about the degree of 99.93 per cent where hydrogen is the chief impurity. The presence of antimony or arsenic is highly undesirable. The purity of the copper is more readily ascertained by the electrical resistance method and has actually been adopted as a measure for its expression.

Of no less importance is the electrical process of refining other metals, such as the gold and silver bullion. Lead, nickel, iron, zinc, bismuth, cadmium etc., are all metals that are mined in great quantities in this country. In refining them, the electrical processes have proved very successful. Each of these refinement processes forms a story by itself and could easily fill a set of volumes. The growth from year to year of the production and improvement in handling the products and ores are a revelation.

The production of aluminum from the ore is one of the greatest electrolytic industries in the United States. The demand and uses of aluminum have increased steadily each year and the improvements in the reduction processes have increased its supply. Metallic sodium, magnesia, and calcium are also produced by the electrical processes at a cost so



Photo, Anaconda Copper Mining Company

ELECTROLYTIC ZINC PLANT, GREAT FALLS, MONTANA

ELECTROPLATING

Photo, British and Colonial Pre. s

low that other methods would be most prohibitive in comparison.

ELECTROLYTIC PROCESSES OF SEPARATING GASES

Many of the elements which exist in the form of gases are most essential in our industrial processes of to-day. The use of oxygen in conjunction with acetylene gas is a means by which the most obdurate steel yields as does the pine board before the rip-saw. The extensive use of hydrogen as a flotational gas for inflating balloons and dirigibles has demanded cheaper processes for its segregation. "Nitrogen from the air" is the new slogan of the engineers to replace the rapidly diminishing stores of it as nature has heretofore supplied it. The arts of agriculture and of war are each handicapped by its present shortage. The latter use we would by all means discourage if the nations of the earth would lay down their swords and firearms, but the art of tilling the soil and reaping one hundredfold depends most intricately upon our supply of nitrogen in suitable forms for the plant life of the earth to assimilate.

The *fixation of atmospheric nitrogen* processes are now being resorted to as methods whereby the vast and inexhaustible supplies of nitrogen of the atmosphere may be made available in the forms of nitrates and nitric acids. The two chief constituents of the air are oxygen, roughly 20 per cent, and nitrogen as a dilution medium about 80 per cent. On the basis of the weight of the atmosphere being fifteen pounds to every square inch of the earth's surface at sea level, there would be in a square foot of surface up to the limit of the atmospheric existence about 1,728 pounds of nitrogen, or

very roughly a ton of nitrogen to every square foot of surface on the earth. Just think of the billions of billions of tons of nitrogen in the United States alone. By mechanical and electrical processes this inexhaustible supply is now being tapped for the benefit of man.

The nitrogen in the gaseous form cannot be utilized in any practical way. In order to make use of it, it must be combined in a compound form with other elements. It may be in the form of nitric acid or it may be in the form of nitrates, that is, certain salts that make a very convenient combination or union with nitrogen. The whole problem boils down to the issue of how best to accomplish the results desired. One man invents a process of one method to accomplish the desired end, it is put into practical operation and the necessary improvements and renovations of the method are added as time goes on, and the limitations of the equipment are found. Then some other individual devises another scheme to accomplish similar results. This is likewise put into operation. Soon there are many methods of manufacture of products that meet with more or less success. Competition makes keen rivalry in the production, causes intense study of the elements of manufacture in order to save and cut the cost of production.

There are, in general, two ways of getting at the nitrogen supply in the atmosphere: one is a mechanical process of liquefying the atmosphere and then separating out the nitrogen from the oxygen; and the second process is a purely electrical one, in which the atmospheric nitrogen is burned under the intense heat of the electric arc. The former method is, of course, quite old, since the scientists

of many decades ago succeeded in making *liquid air*. The famous physicist Dewar worked extensively along these lines and invented his tubes which came down to us as the *thermos bottle* of to-day for conveying the product here and there. The mechanical method employed compressors which compressed the atmosphere to a marked extent. This compressed air was then allowed to expand through a nozzle into a chamber.

Whenever such an expansion process is permitted, it is a striking characteristic that the process of expansion absorbs heat from the surrounding bodies. That is, it forms a refrigerating process. In this way fresh and new supplies of air may be cooled after which they are compressed. If this air is now permitted to expand, it will produce a very much lower temperature than the above expansion process, because it had a much lower value of temperature to begin with. By continuing this process of cooling and compressing by the accumulative process, liquefaction is the final product. The oxygen and nitrogen may here be separated by various processes.

In the electrical process the true reactions are practically thermal and not electrical at all. The heat of the arc, because of its extremely high temperature, is used simply as a means of causing the nitrogen and oxygen of the air to unite. Any other means of producing the high temperature would give the desired result. The combination of the oxygen and nitrogen of the air is thus caused at the high temperature. The product of air and nitrogen oxides must now be very rapidly cooled and treated with various baths in order to get the nitric acids, nitrates, or nitrides, as desired. In the

cooling process the reverse process takes place, that is, the nitrogen oxides have the tendency to, and actually do, dissociate into nitrogen and oxygen. This dissociation takes place in proportion to the time of the cooling. The desired product, namely, *nitrogen oxide*, increases with the inverse time element in the cooling. So the more rapidly that the cooling can be effected the more efficient will be the production. Therefore production depends not only upon the degree of high temperature possible, but as well upon the rapidity of the cooling process.

An electrical process for fixing nitrates was established at Niagara Falls, where power could be purchased at an attractive rate. The type of furnace used there was the so-called spark type, where electrodes were mounted upon a wheel which revolved them rapidly past similar stationary ones. By this means about 7,000 sparks per second could be obtained. This process was tried for many years, and finally because of failure to become a commercial institution the scheme was abandoned. In Norway, however, a system has been in commercial operation since 1905, and its success is now assured largely through the fact that electrical energy can be secured at the rate of 0.094 per cent per kilowatt hour.

CHAPTER XIV

APPLICATION OF ELECTRICITY ON MODERN BATTLESHIPS

AMONG the applications of electricity thus far considered, it may be stated that none are so self-contained as the electrical system on one of our modern dreadnought battleships. This consists of a complete electrical generating plant of large capacity, capable not only of driving these huge ships at a remarkably high speed, but of facilitating the innumerable activities the various departments of these vessels are called upon to perform. As a great engine of war and stabilizer of the affairs of the nations, the battleship of to-day plays a most important rôle. The nation with the greatest navy, other things being equal, has now a marked advantage over nations not so adequately equipped.

With the advent of the aeroplanes during the recent war the effect of the navy was diminished to a certain extent, it is true; but we must not discount in our rash judgment the true facts in the case that the navy is a most potential factor in the control of the affairs of nations. Any aggressive nation will ponder with care and will analyze with most thoughtful attention the points of vantage of her imagined or real enemy. Not even the most daring burglar of these days will act rashly in

the face of a six-shooter leveled at his head. His respect is high for the potential advantage of his adversary.

In the most efficient operation and control of battleships with their auxiliary apparatus no one factor has been so influential in raising the standards as has the electrification of the mechanical operations. The high speeds, the skill in maneuvering, the ease of control, the decrease in weight of propelling machinery, the cleanliness, the decrease of noise, the increased mechanical functioning of auxiliary devices, are all by-products of the new type of power application. The electric service has so conclusively proved itself the superior of the the steam-engine control and drive that all dreadnoughts now built by the United States navy are constructed and equipped for electric operation.

The first trial made by the navy to test the utility and practicability of electric power drive, control and operation of auxiliaries, was made on the U. S. collier *Jupiter*. This renovation of the operating methods of the ship propulsion was undertaken only after considerable discussion and heated debate. It has been generally true that the application of electricity to industrial processes of today has gained the victory only through the hard-fought battle against the inertia of the intrenched system.

After the trial runs were made with the *Jupiter*, equipped as indicated, and most accurate tests had been obtained, the superiority of the new form of propulsion over the mechanical drive was quite obvious. It was thereafter kept in continual service and given the hardest kinds of tests only to find that the life and satisfaction of operation were

beyond the highest expectation of even the promoting engineers.

Of course, the equipment used in the early application of electrical drive was not without fault. The motors had only one inherent speed, the variations of which could be brought about by varying the generator speed or by changing the motor resistance. Such limitations were not without criticism where cruising speed and full speed conditions were not most efficiently controlled. The later designs for such service employed a double system of poles which could be used on the motor; one set giving best speed conditions for cruising, whereas the other pole system would increase the natural speed of the motor for most efficient operation at high speed. Variations in speed from these two natural values could be obtained by changing the frequency of the supply source.

The first battleship to be equipped for trial with the electrification machinery, as a result of the highly satisfactory performance of the U. S. collier *Jupiter,* was the U. S. ship *New Mexico,* the flower of the navy at the time of her construction. She is still one of the finest ships we own, a superdreadnought of the highest caliber. Can you conceive of a power plant sufficiently large and capable to supply power for the industrial uses, for all the lighting and railway and street car service of a city of 100,000 inhabitants? Such is the size of the power plant housed by the *New Mexico.*

This leviathan of the high seas weighs 32,000 tons. When operating at twenty-one knots per hour 28,000 horsepower are required. She carries twelve fourteen-inch guns, mounted three to each turret, twenty-one five-inch guns, four three-pound

rifles and four anti-aircraft guns and two torpedo tubes. There are eight thirty-six-inch searchlights which may play powerful streams of light into the darkness of night. The ship length is 624 feet, with a height of 120 feet from the crow's nest to the water edge—the height equivalent of a ten-story building.

The propelling medium consists of a system of four propellers, each driven by an individual motor. Each of these motors is rated at 7,000 horsepower capacity full load, and is twelve feet in height. They are supplied with driving energy from two huge turbo-alternators of 13,000 kilowatts, each a unity power factor. The supply of fuel is conveyed to the fuel bunkers not by the dirty, slow process of coal hoisting, but by the medium of a huge six-inch hose, the fuel being oil. Convenience, quickness of motion and cleanliness are the natural assets of the type of battleships here described.

Other applications of electricity on this huge ship are found in the electric lighting, hoists, ventilation, machine-shop operation, carpenter-shop operation, laundry purposes, restaurant service, printing machinery, turning turrets, pointing and training guns, operating water-tight doors and hatches, and refrigeration machinery. Many of these points will be considered more at length in the following pages.

The specific application of electricity on shipboard that most deeply affects the general efficiency of the navy is that of electric propulsion. The other uses are highly desirable and afford conveniences and assist in cleanliness, but are not necessarily essential in fighting. Of vital impor-

tance in the drive of a battleship is the speed of the propeller and that of the engines. Ship propellers operate most efficiently at a speed of 125 revolutions per minute. If the speed is run much higher than this, the water is churned by the propellers—a condition which retards the movement of the ship rather than aiding it.

The speed of the steam turbine, however, is most efficient at 2,000 to 3,600 revolutions per minute, depending upon the type and size. If the turbines are used to drive the propeller shafts, it is obvious that satisfactory operation is obtained only when the engine or turbine is connected to the propeller through the medium of a set of reducing gears. In this way the turbine may operate at its most efficient speed, and by the proper reduction gearing obtain the most efficient propeller speed. Such turbine or marine engine drive is used on many of the older types of battleships and other ocean-going craft. This means that the engines must be located well toward the middle of the ship, where the room is ample to house them. A very long shaft must then run to the rear to operate the propeller. A tremendous weight is in this way introduced, since such a shaft must be of huge proportions in order not to be unduly strained by the long transmission of energy. Furthermore, room that could be otherwise most valuable is utilized for the length of the necessary propeller shaft.

In the case of the electric propulsion, the turbine and generator which are relatively very small because of the high speed of their operation occupy little space. These are located in the middle section of the vessel where the boiler equipment is placed and where the greatest protection is afforded

against attack from the enemy. The transmission of the electrical energy may then be accomplished by means of cables to the motors which are located in the extreme rear sections where the shaft length may now be reduced to a minimum.

There is a remarkable economy of space and weight due to such a system in comparison with the mechanical transmission of power from the engines to the propellers. Furthermore, in the case of the electric drive, the control of the machinery is affected by means of regulation of the motor and generator. Reversal of the propeller rotation can be affected without disturbing the turbine operation. The equipment on a switchboard affords perfect control over certain types of maneuvering. Sometimes the turbine speed is regulated to get more refined control. All of these factors operate, however, to increase the satisfactory results of the system.

The many auxiliary devices that are associated with any power-house system are also operated on shipboard by motor. Such operation serves to give cooler conditions in a part of the ship where the only breath of fresh air comes by virtue of forced ventilation. The hold of a ship is usually extremely hot, crowded for room, and compact in construction, because of special marine design to accomplish this very purpose. The one thing that constitutes the limitation of the ship activities is the lack of room. The turbines or engines exhaust the great quantity of steam into condensers where it is condensed to water and used over for boiler feed water. There must be pumps to circulate the cooling or condensing water, to remove the condensate or condensed steam, to force the

feed water into the boilers, and to eject any air from the condensers which may have entered in the steam.

The passage of clean, fresh air into the many stories below deck may be accomplished by installing blowers with the necessarily large flues to carry the cool, fresh air to the lowest points. This air becomes heated and rises. This relief is practically essential to continued life in such dungeons where the light of the sun never penetrates. The ventilating system is operated and controlled by electrical devices. Motors are, of course, used for the driving power.

By no means are the workshops of these great ocean greyhounds a small department or of little significance. In the case of emergency these shops are depended upon to execute certain work, and the survival of the ship may depend upon the performance of this department. The equipment of standard machines is therefore electrically driven, since no power is so well adapted to machine work as is electricity. Even a printing establishment is a function of the latest types of ships, where the world news gathered from the highways of the air, perhaps in mid-ocean by means of the wireless receiving stations on board, may be placed in print for the perusal of the sailors. These and many other comforts are designed to give a certain degree of satisfaction to the sailors in order to keep them in service.

Not least among the necessities required to keep the man aboard in good spirits, by providing him with good things to eat and cold water to drink, is that of the *refrigeration system.* These plants require a motor or other drive to actuate the com-

pressors for the ammonia or carbon dioxide gases, which are the means for absorbing the heat, when they are released from high pressure and permitted to expand to normal atmospheric pressure. The absorption of heat here involved may cool brine that is caused to circulate throughout the large larders and storage rooms. The freezing of water into ice is also accomplished in the same general manner by circulation of the brine.

The massive water-tight doors and hatches which may operate to inclose the ship from the most violent storms are operated by electric motors. The requirements of all these motors are most rigid in regard to the design for waterproof qualities. They are inclosed in an iron casing in order that they may be water-tight. The test that they are subjected to is that a stream of water under thirty-five-foot head is played upon the motor at a distance of ten feet from it, without permitting any leakage within. Such motors are, therefore, protected from the very destructive effect of the salt-water spray that might come in contact with them. The atmosphere, saturated as it is with salt air, is very corrosive and injurious to the insulation of the motor windings.

One of the recent innovations in the use of electricity in the navy is its application to cooking and baking. The old-time method of employing charcoal fires, coal fires in ranges, and steam in the great steam kettles, has practically had its day in naval service. The marine authorities recognize the dangers of fire hazard with these old-time methods. The inconvenience, the space occupied by such fuels, and the attendant danger with the old-time system have all reacted in favoring the use of

electric cooking and baking. In this method the snap of a switch only is necessary to bring the fuel. It is clean, sanitary, convenient, dependable, easy to regulate, invariable in its application and uniform in its amount of heat. By the use of electricity less material is wasted by spoilage; because of the regularity of heat there is less shrinkage of food material, and better quality of production. All of these points have been carefully analyzed and found to be true.

The elimination of smoke and gas so inextricably associated with the use of coal, charcoal, and wood for cooking purposes, is a matter of great moment. The use of electric ranges is fully justified from this point alone. The rapidity with which cooking and baking may be done, moreover, means a considerable saving in the size of the culinary department, a most important consideration. To supply cooked food to a certain number of men fewer ranges and smaller quarters are possible with electric cooking than by the old-time methods. The crew and officers on a modern man-of-war often reach the large number of 1,200.

In times of action and in target practice the great guns and turrets of guns must be moved in establishing the necessary aim. The use of motors for this elevation and training is a matter of speed and convenience that could not be obtained by manual operation. A signal system is in vogue by means of which the gunners and operators are informed as to the setting of the gun direction. This information comes by virtue of the operation of the range finders.

These guns must be fed by certain divisions called the gun crews. These men, located in the

magazine section of the ship, place the explosive charges on elevators or conveyors and lift it to the deck where it is nearest to the guns. Here a part of the gun crew place it in the guns behind the projectile. The projectiles are also conveyed and placed in the guns in a similar manner. Where the shells for smaller guns have the projectile and explosive all contained in one shell as a huge rifle cartridge, the process of loading is rendered more speedy and simple. To a turret the standard crew for manning the guns and for handling the ammunition is composed of ninety-six individuals, each having his own particular station and function to perform. The conveyors and elevators are operated by electric motor power and must be absolutely reliable.

In the large fourteen-inch guns 500 to 600 pounds of explosive is used for a single charge and the projectile weighs from 1,200 to 2,000 pounds. These heavy weights require considerable energy to lift and transport with the speed required under actual firing conditions.

The electric signaling system on board a battleship is a phase of the electrical system which has tremendous importance attached to it at any period and especially at the time of engagement. A telephone system is installed in all officers' quarters, and to the chief points of vantage, such as the guns, the crow's nest, and the like. Then, also, systems of electrically operated dials with certain indications attached are used for giving directions for control of engine speeds, for maneuvering, for training and elevating guns, and the like. These circuits must be carefully laid and protected throughout by means of lead-covered cable, so that

failure will not result from the corrosive action of the salt air.

In general, though, the signaling systems found on shipboard vary very little from those considered in a previous chapter. This application is simply one more to the already enormously long list of uses for these devices.

CHAPTER XV

MISCELLANEOUS ELECTRICAL APPLICATIONS

THERE are many special applications of electricity to various activities that are in themselves more or less important, but which do not make up separate divisions of the electrical science. For that reason they will be brought together in the following chapter. Many of them are of exceptional ingenuity and interest to the practical man and to the mechanic in general.

FROZEN WATER PIPES THAWED BY THE USE OF ELECTRICITY

The winter season of the northern countries is looked upon with dread by the owners of homes where the many pipes conveying water, gas, and sewage are subjected to the dangers of freezing. The high cost of plumbing work in these times of soaring prices makes a greater menace than ever before of this one great objectionable feature of the winter period. Furthermore, the high cost of labor is oftentimes secondary to the fact that when most needed it cannot be secured. At the time of a very cold spell the demand for labor is great, and again the time required to perform the work by applying external torch, injecting steam, and the like, is often expensive and without results. Experiences of this nature, where pipes have burst in hundreds

of homes, have caused the owners and tenants such extraordinary discomfort that any process which hastens such work has been welcomed most enthusiastically. Except in a few cases, however, since the process is still comparatively new, no such enthusiasm has been accorded the application of electricity to accomplish this very thing, in a way that creates no dirt, no removal of floors, no dangers of fires, and requires but a few minutes of time.

The principle involved in such application is, indeed, not a new one. Throughout our book many enumerations of it have been made. Do you remember the principle of heating by electricity as it passes through a resistance? There is the secret. You are well aware of the heating created by the electric toaster, by the electric light bulb, by the electrically heated flat iron, by the electric range, and the many other electrical conveniences of this nature. In each of these, and in fact in every circuit that carries the flow of electricity, there is a resistance offered by the circuit to the flow, and it takes a greater and greater pressure or voltage to force the current through circuits having greater and greater resistances. The heat that is produced in every case is proportional to the product of the resistance of the circuit and the square of the current that flows through the circuit. The process of heating then is to have a certain resistance and to send through a large current. The heating increases very rapidly as the current is increased, because, as just stated, the heating increases with the square of the current. That is, if you double the current flowing through a certain circuit, the heating increase will not be doubled but rather

made fourfold. And if the current is made four times greater, the heating is rendered sixteen times greater than before.

To apply this principle to the service required of it to assist in thawing out water pipes is most simple. Just apply a current of electricity through the pipe that is frozen, making it a part of the electrical circuit. This circuit, like any electrical circuit, has a certain resistance. The current flowing causes the pipe to heat, and in so doing makes the ice melt. Furthermore, some of the electricity actually flows through the ice in the pipe, which has a direct heating effect. Such application of heat is the most efficacious of any heating system, since the generation of heat is uniformly applied all around the pipe and through its entire length, and even from within, due to the resistance of the ice itself.

Knowledge and care must be exercised in applying the electricity to the system. The full voltage must not be applied directly to the pipes, or a short circuit would result in the blowing of fuses and incapacitating the circuit for further use until repaired. The process should not be applied by the average individual, as great harm would be the result through ignorance of the correct operation. But licensed operators should be permitted to apply the system in order to relieve the great congestion of work in the times of extremely cold weather. There are on record many instances of the successful application of electricity to relieve the cities from the complete paralysis resulting from frozen water, sewage, and gas pipes.

A large six-inch main of 1,700 feet length in the East River at New York is recorded as having

been frozen. It required a time of thirty-six hours and a power expenditure of 750 kilowatts to relieve this condition. The pipe was laid in the bed of the river and was surrounded by salt water, which gave most difficult location for the work of thawing. The heat was carried away so rapidly by the great quantity of water surrounding the pipe that the task of melting the ice was rendered very difficult. In a case of this type the operators would start back at the pumping station and test out section by section as they progress, and as sections are met with having a frozen portion, it would be opened up before going further. Such procedure is followed until the ends of the system are reached.

SIGN AND DISPLAY LIGHTING

There has sprung up in this country, more than in others, a desire to display advertisement in most spectacular and amazing ways. The use of the press and numerous magazines, circular letters, individual bulletins, street car and train signs, while all used to the very limit of the space permitted, seem not sufficiently attractive and novel to satisfy the departments in charge of the advertisement of the various products: As supplementary means promoters have thus originated and erected at conspicuous points of buildings great electric signs involving most complicated operations and configurations of lighting to attract the public eye. Who has not been held fascinated by the most beautiful and artistic designs of lighting displays in our great cities. A poor city it is, indeed, to-day which does not boast of its "White Way," and yet what is the "White Way"? Is it the street that the city itself chooses from among all the others, to equip with a flood of

artificial illumination? Not at all. Every city, because of its theatrical centers, cafe and hotel districts, and certain industrial activities, develops intensely along one or two main thoroughfares. These very naturally evolve into the "White Way" sections. In general, the illumination of such districts at the expense of the city is really inadequate. The expense of the great flash and glare of lighting is borne by the interests that display their specialties to the public. The attractive and intense flaring of the arc lamps which mark the prominent moving picture theaters, the colored lights of the announcement and feature displays of the theaters, the works of art in window display with its variety of electric lighting marking each, are distinctive from all others; all cooperate to make a most delightful effect.

Superimposed upon this glory of illumination in the street comes the ultraelaborate effect of the sign lighting. Consider Broadway, the World's great White Way, stripped of her signs and what would there be left? The throngs would still pulse back and forth and the institutions would still thrive, but with the passing of these marvels of genius would also pass the fascination, the glory, the enthusiasm, and the spirit that for so long has marked the affairs of that street. How dear to the Broadway man has grown that vast and miraculous monument to the genius of the illuminating expert—the Chariot Race—which for years entertained his attention in his nightly perambulation! How tenderly and how longingly he refers to it as of the memory of the past friend! The antics and calesthenics of the Wrigley Triplets now occupy the center of attraction above Times Square. There is the ex-

pression of great ingenuity and ability in electrical display. This massive sign employs the use of over 18,000 Mazda lamps, and requires several electricians to attend its operation and maintain its upkeep. Such a sign costs between $50,000 and $100,000 to construct and the cost of operation may reach the fabulous price of $100,000 a year. Of course, signs of less elaborate configuration and structure run less in cost.

The great Bull Durham at 51st Street ferociously impresses the joy seekers that throng the "White Way" with the majesty of his presence. His contortions and actions are less complicated than some that have appeared along this great highway of renown, but yet, when viewed in comparison with those seen elsewhere, this sign measures up to gigantic proportions. It is a very peculiar trait of the human mind that its measure of stature is so erratic and entirely a matter of relativity. Many most worthy features in various institutions of the world are belittled by the overshadowing greatness of other near-by institutions of vast proportions. So it is with many of the "White Way" insignia—they are rendered insignificant by comparison with the near-by giant.

The small signs that are used over the store fronts many times introduce unique and attractive features. It is not absolutely necessary that the sign be of such enormous proportions to make an impression upon the esthetic taste of the individual. Many times the name of a company only will be outlined in small incandescent lamps which are caused to light at succeeding intervals to spell out the entire name, which may be followed by various characteristics such as blinking the whole name.

Such devices are attractive and serve their purpose of securing the momentary attention of the ever shifting public as it sweeps along in the ceaseless pace below. Such mechanical variation in the time element of the sign operation is very ingeniously accomplished by a motor-driven drum which revolves at a slow speed, makes and breaks contacts with fingers that bear upon the proper strips of the drum. Almost any complication of operations may be effected through the proper timing of these make and break periods with the circuit contractors. For example, Figure 207 shows how a devise may operate to perform the blinking of a circuit.

Interior decoration with small light units has gained more and more in popularity and utility with the increasing demand for display. The great department stores during the Christmas holidays expend vast sums of money in equipping great attractions for the children by way of advertisement to gain the patronage of the public. Very elaborate programs of Fairyland and Toyland replicas are put into execution. A simple and delightfully beautiful effect for Christmas trees either in small home sizes or for large sizes may be realized by the illumination secured through a variety of tiny colored lights which are distributed throughout the tree and caused to blink or light and extinguish at certain predetermined periods. Such lights may be connected ten or more in series on one circuit and by a thermal switch which may be screwed into any standard Edison socket, be caused to blink with any desired time interval in a very attractive manner. The possibilities of display lighting are almost as unlimited and boundless as the sea, and in truth one

rarely sees a duplication of display, each system usually being characterized by its own features.

ELECTRICAL PRECIPITATION

Mention has been made on one or two earlier occasions of a method whereby smoke may be filtered from the gases that issue from the top of the smokestacks of industrial plants and the smoke caused to fall or precipitate into collecting bins where it is periodically removed. Since this process is growing rapidly throughout the industrial world, a few pages to consider the elements herein involved by such a system may well receive attention.

First of all, we are certainly all agreed upon the fact that the heavy dense black smoke which for hours each day pours forth from the great stacks of the industrial plants is an annoyance and a nuisance to the community. For long ages past, it was looked upon as a necessary evil and that control of such annoyance was beyond human power. Because of the localization of certain types of industrial plants in a certain community it was doomed to be enveloped in an atmosphere of soot more dense than the London atmosphere of fog. Pittsburgh gained the distinguished but not enviable name of the "Smoky City" because of the enormous volumes of smoke poured forth from the busy steel and smelting plants.

As you probably all know the so-called smoke is really in part the unburned product of the coal which is carried up the flues by the hot gases of perfect combustion. That is, as the coal burns, some of its constituents change into a burned and furthermore useless residue, called the *burned product*,

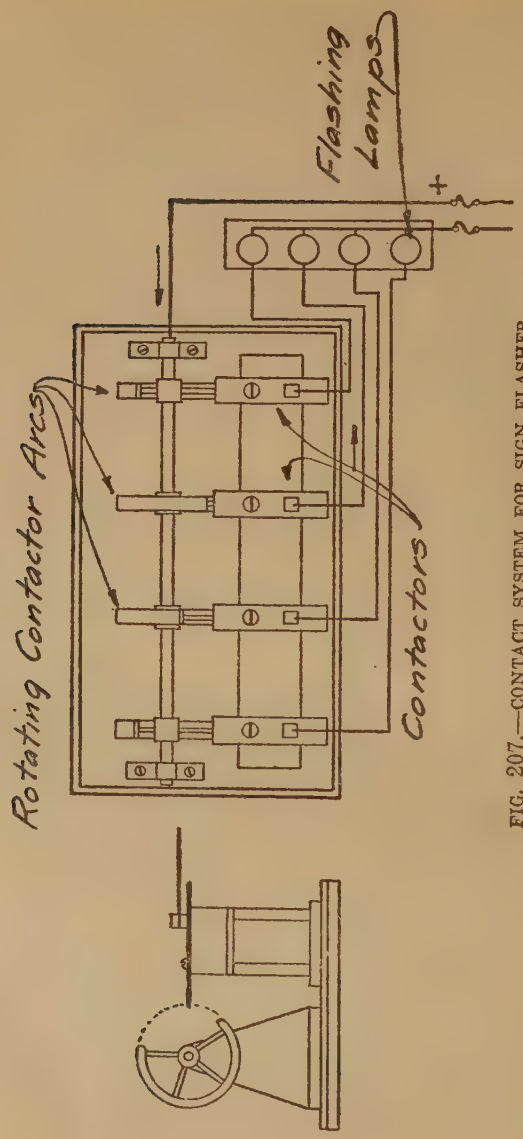


FIG. 207.—CONTACT SYSTEM FOR SIGN FLASHER

while other parts of the coal because of imperfection in the mechanical design of the furnace proper does not burn entirely. As it escapes up the stacks, therefore, it represents a waste of valuable material. This escape product is in the form of specks of the black coal, of carbon, and of a tar product. The great number of these particles causes the gases to appear as black as ink. Perfect combustion in the furnace, however, would evolve only a colorless vapor from the chimney. This effect may be readily seen in the case of a railway locomotive which gives forth a pouring black billow of smoke as it proceeds up the grade and the fireman is forcing the fire with a heavy draft and a continuous supply of coal. Then, when the fire has not been recently fed with fuel, how the stack will give forth a very light colored gas showing good combustion of the coal.

In the refining and smelting processes carried on in the mining districts the smelters which are fired with the products of ore together with the charges of charcoal and other forms of heating media give forth voluminous quantities of smoke where the solid particles that constitute the black smoke may not be the coal product alone, but in such cases the particles of the product of the smelting process as well. The smoke may and usually is, in such industries, extremely heavy and continuous. Frequently the product of such smoke contains acids and alkalines that attack and kill every vestige of vegetation for miles around making the environment most barren, dreary, and uninhabitable. Such destruction to plant life renders the living conditions for the employees a problem of no little moment to the plant owners. It calls for increased expenditures from the employer in the way of large wages

to compensate for the lack of the natural conveniences and for improvement of an artificial nature to create some degree of satisfaction among the help.

So far the side of the problem considered has been only from the angle dealing with the nuisance of smoke production; however, great as this problem is, another phase of it of no small significance is that of the waste product that is annually cast out to the disposal of the winds and the disposition of nature. In other words, there is an economic waste continually in progress which becomes greater as the density and blackness of the smoke increases. In the smelting and refining sections for copper, lead, zinc, iron, steel, and the many other metallurgical processes, the by-products of the smoke as above explained may be in the form of acid particles, minute specks of the metal under treatment, besides the carbon and sulphur waste resulting from any coal combustion.

It has been conceived that the recovery of these products that have, since time first began, gone to waste would constitute a saving that would at least pay for the cost of the process of recovery and in so doing eliminate the discomforts of the smoke nuisance. Mechanical means of various types were invented which have made a good start along the highway of accomplishment. Such systems were only partially successful, however, and depended quite substantially for their success upon the atmospheric conditions, and the quality of the products of combustion.

About 1912 and 1913 some very successful research work was carried on by several investigators and methods of electrical precipitation were per-

fected and placed in operation among the various industrial plants. The success of this electrical process of precipitation has caused its introduction into wide variety of plants. It is being used in lead and copper smelters to reduce the metal losses from the stocks; to abate the smoke nuisance in cement plants; to collect potash and the cement dust; in acid plants to recover acid fumes; in rock crushers to suppress the dust annoyance; in iron blast furnaces to recover potash and eliminate the ore dust, in gas plants to remove tar, dust, and lamp-black from the gases; in locomotive round-houses and power plants to remove soot and cinders from the gases, and in industrial processes which manufacture fine powders such as lamp black, zinc oxide, desiccated foods, etc.

To illustrate the economical value of electrical precipitation to such industries, the enumeration of a few examples giving the attendant cost of installation, the operating expenses, and the income from the by-product of recovery will be helpful. A copper smelting company installed an electrical precipitation plant at the cost of $113,900. The annual expenses of labor, power, supplies, and up-keep was $14,600 per year. The value of the copper dust collected per year at twelve cents per pound was $180,018. Therefore, the expenses of installation were paid for within the first year with a comfortable margin. The profit in succeeding years also was insured and estimated at a magnificent amount.

The installation of the necessary equipment for a cement plant cost $180,000 and the operating expenses were about $10,000. The material recovered in such a plant was of much less value than the

copper dust of the preceding example, yet the income for the year in the form of cement dust and potash amounted to $74,325. This represents a highly satisfactory profit and shows the economic advantages of the precipitation processes.

The process of smelting by precipitation treaters is a very simple one. As the waste gases from the retorts and burning chambers pass to the stacks they are caused to pass through the so-called electrical precipitation pipe treaters, which are simply large vertical sections of steel tube or pipe several feet in diameter. Within these steel tubes are smaller tubes resembling those in a boiler set on end, although the individual small tubes are not as small as these, but are several inches in diameter. The smoke must pass in its course to the stacks through these smaller inner tubes of the pipe treaters. A wire runs the full length of each of these tubes and is held directly in the middle of the flues and thoroughly insulated therefrom. The pipe is made the positive electrode and the wire within the negative electrode of the electrical system of very high direct-current voltage. This direct-current voltage ranges from 25,000 to 65,000 and establishes a powerful electric field across the intervening space from the wire to the inner surface of the pipe that constitutes a most effective barrier to the passage of solid particles up or down the flue as the case may be.

The theory of the action that results is given briefly in the following paragraphs. The gases as they pass into the influence of this very intense unidirectional electric field become *ionized*, that is, broken up into positive particles and negative particles. The negative ions are powerfully repelled

by the negative wire and attracted by the positive pipe to which they rush with great force. Furthermore, the positive ions are attracted to the wire and rush across with tremendous velocity. In their travels from wire to pipe or vice versa the ions collide with the solid particles suspended in the gas and traveling with it and impart to them like charges of electricity by contact as explained in the chapter on static electricity. These particles now being charged rush to the pole of unlike polarity, but because of the relatively small area of the wire as compared with that of the pipe the charge density about the wire and its stress is enormous compared with that of the pipe. Therefore the positive particles are negatively electrified and hurled to the pipe where they tend to stick. The same is true of the positive particles. By various methods the accumulation of particles is collected in receiving bins. The electricity and draft may be closed from these precipitation treaters while the walls are rapped to shake the deposits into the bins below, or the walls may be formed in such a way that the particles at the walls may slide down continuously. Where one electrical set must be shut down for repairs or for precipitation the gases must be directed to another set ready for operation.

You have probably already marveled at the very high voltage for a direct-current system, which was said to be necessary to produce the satisfactory field. It may in practice be obtained in two ways. One very common and satisfactory way is to employ the mechanical rectifier method of converting the alternating-current voltage to the direct current. Of course, any commercial low voltage such as 110, 220, 440 volts, etc., may be stepped up to the neces-

sary high voltage value, as 100,000, at the normal frequency of the circuit, be it 60 cycle or 25 cycle. This voltage is applied to a two or four segment commutator which rectifies it to the high direct current value as desired. The commutator must run synchronously with the supply frequency. A very popular method for the necessary plant equipment is as follows: a motor generator unit is used by means of which the supply system drives a motor which in turn drives the alternating-current generator. This voltage is stepped up by a specially designed transformer to the necessary high voltage. This voltage is rectified by a commutator mounted to an extension of the generator shaft just as any commutator is used to rectify the alternating-current voltage. This high direct voltage is then applied to the electrodes of the precipitation treaters.

There are, of course, many compartments in the treater, and each of these may be supplied directly by an individual set of electrical equipment at the power house of the precipitator system, or all may be supplied by one large set which generates the energy for the plant. In this case the individual treaters may be isolated by disconnecting switches. The former system insures greater reliability and has gained general favor.

Unusually severe conditions are imposed upon such a system as that involved by electrical precipitation. The extremely high voltage present causes surges to be easily set up in the treater circuit. They produce violent strains upon the end turns of the transformers which must, therefore, be thoroughly protected. It is customary to build in an impedance coil at the end of the condenser

type terminals and also to have one between the base end of the terminal and the transformer coil within the case. To further protect the end coils, they are most heavily insulated to prevent a breakdown at these exposed parts. The generator also has a condenser across its terminals for the double purpose of smoothing out any voltage disturbances and to short-circuit any high frequency oscillations that may be forced on to this circuit. The lines are insulated in the most efficient manner possible, and in fact every precaution is taken to eliminate any possibility of danger by breakdown or rupture of the system.

VEGETATION GROWTH EFFECTED BY ELECTRICITY

About two centuries ago it was discovered by a Scotchman that plant life was stimulated in its growth by the presence of a high voltage electric field. In other words, if the condition that exists during periods of thunderstorms, where there is a high voltage difference between the clouds and atmosphere and the earth, could be maintained at all times, plant life would thrive and flourish to a greater extent than it does at present.

Over one hundred years later a systematic study of the effect was undertaken in European countries and it was then observed that the ordinary garden and field vegetables and products were benefited and an increase in production of 25 to 45 per cent established by the presence of an electric field. The methods pursued in the experiments, however, were not adaptable to practical ends since horse or power cultivation could not be conducted because of mechanical obstructions. A network of wires was spread over the section and held a few inches above

the ground with drop wires suspended having sharp points and barbs. A static machine was used to supply the energy to this system and the points readily charged the air and passed to the ground.

In 1906, a more careful research was begun in England called the Evesham Experiments in which the great physicist Oliver Lodge took an active part. Later the Department of Agriculture of the United States Government took up the investigation to analyze the condition affecting the increased production of plant growth and to study its feasibility. At present a twenty-acre section may be covered by a twenty-one pole installation. The electrification network consisted of bronze or steel wire run at least fifteen feet above the ground to permit proper cultivation. The potential of the system is maintained at a voltage of 50,000 to 75,000. This corresponds to the average potential difference present during thunderstorms; and on a quiet day its discharge can be distinctly heard. The source of the energy is by means of an induction coil which is rectified through the application of several Lodge or other type vacuum tubes or electric valves. The power consumed by the outfit for twenty-five acres approximates from 400 to 600 watts. This would cost from six to nine cents per hour of operation where energy is at the rate of ten cents per kilowatt hour. Of course at present the proposition has no practicability on a large scale, but it may prove of great value in the future.

Because of our decreasing supply of nitrates it is becoming necessary to augment our supply by fixation of nitrogen from the air. Possibly something might develop along this line where the electrical process may be applied in this way rather

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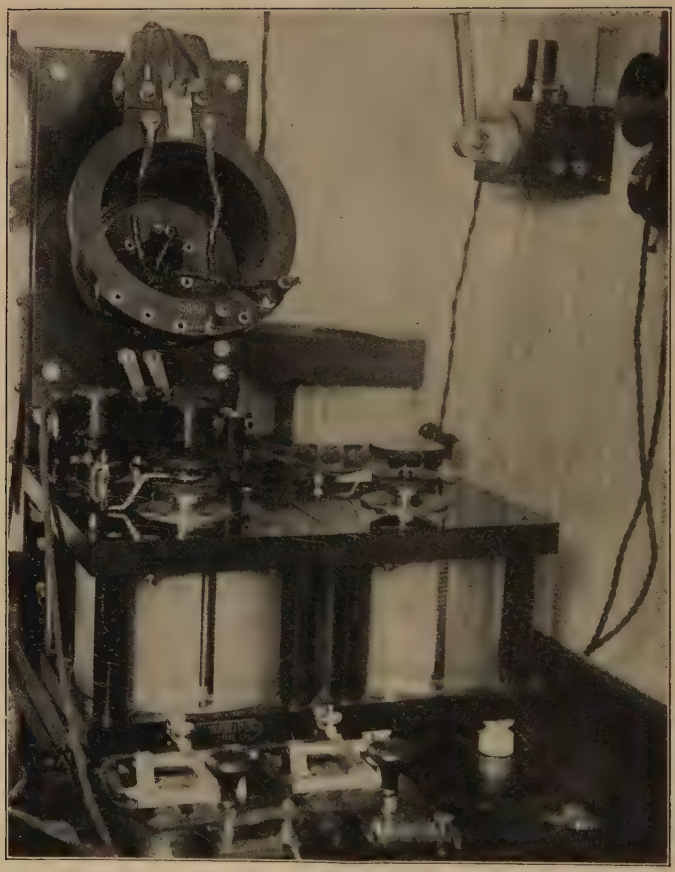

WIRELESS APPARATUS OF A LARGE STEAMSHIP

than by first extracting by electrical means the nitrogen from the air, only to fertilize the ground later with its products. In other words, it may prove an economic asset to install such a network system and electrify it than to supply the necessary nitrates.

OZONE—ITS PRODUCTION AND APPLICATION

Ozone is a gas that people are prone to remark about with very little knowledge or familiarity to back up their observation. The properties of ozone are that it is colorless as it exists under normal conditions, but as it is compressed or liquefied it takes on a deep blue appearance. It has an odor like that of a mild chlorine gas and is not unpleasant to smell. It takes a very great pressure, about 125 atmospheres, to liquefy it.

The ozone is actually oxygen with a slightly different molecular formation, however, than the oxygen contained in water. The ozone may be obtained in many different ways, among which are: (1) by electrostatic field; (2) by electrolysis; (3) by chemical action; (4) by ultra-violet rays; (5) by evaporation of water, and (6) by incandescent solids. The commercial method in most common use is that of the electrostatic field. The air when broken down and ionized by a powerful electrostatic field renders a formation of ozone. The air is taken in between plates which are highly electrified by a voltage ranging from 5,000 to 20,000. The ozonated air is then fanned out into the surrounding space. The chief uses of ozone are (1) as an oxidizing agent; (2) for ventilation; (3) for its disinfecting power; (4) for bleaching, and (5) for water purification.

Its use for ventilation is most widely known to the public, since many theaters employ it as a

means to purify the vitiated air in overcrowded houses. The power that it has of destroying odors that accumulate from the exhalation process of many people in a room is quite remarkable. Professor Bass recently conducted experiments on school children, and from the results established the fact that the addition of about one part of ozone in a million parts of air, when the air supply is very small, determines the difference between tolerable and intolerable conditions.

The use of ozone for bleaching is proving very successful. In the older processes chlorine had been the stable constituent for the bleaching of cotton, linen, and silk fabric. The chlorine was mixed in great vats and emitted voluminous fumes which were very objectionable. The gas, too, was poisonous and the work in general most distasteful. Ozone, however, accomplishes the work most satisfactorily, is in no way poisonous and needs no great storage room or vat mixture. It is used for bleaching oils, fats, tallows, and waxes, which may be made tasteless, odorless, and otherwise highly purified. Ozone stands foremost as a purifier and foe to any putrefaction or growth of malignant bacteria. Its most extensive use at the present time is its application as a purifier of water. It is insoluble in water; a condition which insures that it will not be held in any quantity in the water as so many reagents are. Furthermore, ozone is a nonpoisonous reagent, a fact that renders its applications much easier. Not only does ozone attack the bacteria of the water and render the sterile effect desired, but it removes as well all distasteful odor of decomposition or organic defilement. The ozonated water must be filtered, in which process about 97 per cent of the

organic matter is removed. The ozone is forced into the water and thoroughly dispersed through it by means of mechanical processes of one kind and another. The cost of such water purification is very reasonable, being about $7 per million gallons.

BLOCK SYSTEM OF RAILROAD SIGNALING

Since the upbuilding of all sections of our country has not only increased the railroad traffic to huge proportions, but has also increased the problems attendant upon the efficient and safe handling of the great number of trains that daily operate over the lines, the importance of protection and safety to the traffic has become paramount. "Safety First" is the slogan of the times and so important a slogan is it that all the laws for its enforcement should be executed to the letter. There is no more sad and gruesome sight than a train wreck where cars are splintered and demolished and where life has been surrendered because of the irresponsibility and carelessness of certain officials.

The trend of the times has been to take the power and responsibility as much as possible from the individual and make operation as nearly as possible automatic in control. No one system has insured the safe operation of trains with a very minimum of danger and accident as has the operation of the *block signaling system,* as is now being employed almost universally on both steam and electric lines. The system may be classified under three general heads, as follows: (1) manual, in which the signals are operated by hand, according to information received by phone or telegraph; (2) controlled manual, in which electrical means are usually employed to

afford cooperation between the signalmen operating the block from either end; (3) automatic, in which the signals are power-operated by the trains themselves as they pass over the sections of a block of the rails.

In the *manual type* of block system signalmen are employed who control the signals through communication one with the other, through bells, lights, phone service and telegraphic communication. The various blocks may be of any desired length, depending largely upon the frequency and amount of traffic. A train must never enter upon a given block until the signal to "proceed" is indicated by the signal arm or light. This is controlled by the man at the beginning of that block. The signals at the second block cannot be set until the first office has ascertained from the second office that the second block is clear. The signal is then set for that block. In case the block is not free, the signal is set against entering that block. In the case of single track, the protection must be for trains from both directions. The train dispatcher gives the orders along the line for the movement of trains that are in addition to those scheduled.

The *controlled manual system* provides electrical operation of levers that control the signal arms. These, in turn, are controlled through the operation of buttons, but can take place only through a certain sequence of operations that require the cooperative attention of the signal men at the beginning and end of the block before the signal can be released and set at the entrance to the block. There are many and diverse methods and equipments employed for the operation and control of the various types of service demanded.

The *automatic block system* is by far the most advisable and practical method. It is rapidly gaining in popularity and its success against accident is a measure of its ability to protect. The means of its operation lie in the electrification of the track system. In case anything is wrong on a block, even to the failure of the electric signal source of power, the block sets against "procedure" on the block. This gives absolute protection and avoids any chances being taken. The *blocks* are formed by certain lengths of track being bonded to form good electrical connection. Each section is then insulated from the next similar section by an insulating medium placed between the rail ends. These blocks may range from a hundred feet up to six thousand feet, and each block is separated electrically from the adjacent blocks by the insulated joints in the rails. Each block has an electrical energy source, such as storage battery, gravity battery, and also a track relay, with a series resistance to limit the current to a small value in case of a short-circuit of the rails.

Normally, the battery is supplying current to the rails and relay, the circuit being through the relay and back out on the rail to the battery again. The current which normally flows is sufficient to hold up the relay armature against the pull of gravity, or, in other words, against its own weight. In this normally closed position, armature contacts which may be designated as "A" and "B" are closed. The resistance of the relay may be from four to ten ohms. The current required is usually not more than seventy milamperes, which is 0.070 of an ampere. The contacts, which may be designated "A," "B" and "C", are an integral part of the

system and control the signals at the beginning of the block. If the circuit contacts "A-B" open, then the signal to "stop" is displayed. In the normal closed position of the contacts, the relay being energized, the signal to "proceed" is displayed.

As a train approaches a new block, and observing the "proceed" signal enters upon the block, the car wheel and axle causes a short-circuit to occur as a shunt across the relay, which immediately becomes de-energized and allows the relay armature to drop thereby opening contacts "A-B" and closing "C." This procedure operates the signal and causes "stop" to be displayed.

Such a signal protects this train or car until the last car or axle has proceeded from the far end of the block. One set of car wheels with an axle is a sufficiently good circuit to accomplish the result. As soon as the train has passed from the block, the current through the relay is reestablished with sufficient strength to draw up the armature of the relay and by closing the contacts at "A-B" and opening "C" display the "proceed" signal. At switches for sidings, a short block is there established to indicate that clearance space is available between any car on the siding and the main line rails. Such indication is very important. Any failure of the battery, or a partial circuit from one rail to another because of wet conditions of ties, any tampering with the rail circuit, or a broken rail would set the signal for "stop" on the block. Such precaution is absolutely essential as protection against any mechanical failure.

A low electromotive force is essential on such a system because the danger to unsuccessful operation is reduced since the current leak will surely

not be excessive. Furthermore, with this low electromotive force the breakdown of the rail and insulation between blocks will not affect the operation in the next block section.

In the case of electro-operation of roads, the relays of the block system would be affected by the power current in the return system and, therefore, a revised scheme of operating features of the relay must in this case be made. In the case of a direct-current power system for the cars on trains, the signal operation may be made to respond to alternating-current action only. Where the power system is alternating current, the signaling may be accomplished by direct-current operation or alternating-current supply of a different frequency than that of the power supply. The relays in this case may be made to respond to the signal frequency and not to the power frequency. In some cases the one rail system for the block signaling is employed, the other rail being thoroughly bonded and designed for the return of the power current. The various schemes that have been devised by the engineering experts on the switching and signaling problems are very numerous and exist to meet the most complicated network of railway systems.

GLOSSARY

So popular have become the applications of electrical apparatus in the homes, automobiles, offices, and where not, that the public is constantly making an attempt to grasp some of the more common of the words so fluently employed by the electrical technician. So many of these terms and phrases as used by the layman have been either misconceived at the start or befuddled through questionable usage, that the authors of this work think it well to place at the service of the public authentic definitions or explanations of many of the more common expressions met in electrical practice. Oftentimes, however, a mere definition of a term is unsatisfactory, and a clear conception of its meaning can be conveyed only by a description or explanatory remark.

Actinic Rays.—The rays of light or other forms of radiant energy that affect chemical decomposition.

Action, Local.—An undesirable wasting consumption of the zinc element of an electric cell. It is due to the presence of impurities in the zinc plate which together with the plate in the presence of the electrolyte forms a local cell and wastes the zinc. Its action goes on continuously.

Alternating Current.—An electric current that flows back and forth in a circuit.

Ammeter.—An instrument which will directly indicate the rate of flow of electricity in amperes.

Ampere.—Practical unit of electric current designating a rate of flow of electricity. One ampere of electricity flows through an electric circuit under a pressure of one volt and an opposition or resistance of one ohm.

Ampere-hour.—The flow of one ampere for one hour is one ampere-hour. In general, the product of amperes and time is the quantity of electricity passing a point in question.

Ampere-turns.—A turn of wire through which an ampere of current passes. In general, the product of amperes passing through the number of turns of a coil gives the ampere-turns.

Angle of Lag.—The angle by which the pressure and current differ in a circuit containing resistance and inductance only; that is, the pressure or voltage curve passes through zero or comes to a maximum earlier than does the current curve in an alternating current system. The degrees difference between the two curves is called the angle of lag.

Angle of Lead.—In an alternating current circuit in which there is present resistance and a predominance of condenser effect, the current wave comes to a crest or maximum earlier by a few degrees than does the pressure wave. The degrees lead of the current is called the angle of lead.

Anode.—The plate of a cell into which the current flows from the external circuit. It is commonly termed the negative terminal of the battery.

Armature.—A piece of soft iron placed across the poles of a magnet. It is sometimes called a "keeper." It preserves the magnetism of the magnet.

Armature, Dynamo.—The part of the dynamo-electric machine in which the E. M. F. is generated. The terminals of the armature are usually connected directly to the external circuit.

Armor of Cables.—A protective sheath of metal surrounding an electric conductor or system of conductors.

Arrester, Lightning.—A device for protecting electric machinery and instruments from the dangers of lightning disturbance.

Atmospheric Electricity.—The electricity which is practically ever present in the atmosphere being accumulated by clouds and dust particles. It exists in greater quantities in the upper strata than near the earth. It is greater in still air than in rapidly moving air. It is stronger in winter than in summer.

Atom.—The smallest particle of an element of matter that combines with others to form the least particle of a substance. For example, the smallest particle of salt that can exist as such is made of one atom of a metal called sodium combined with one atom of a gas called chlorine. The sodium and chlorine are elements. There are about eighty-three elements so far discovered in the universe.

Attraction.—Literally the act of drawing together. In science it is used to signify an effect of drawing together electrons, atoms, molecules or masses.

Automatic Regulation.—A type of control which automatically by means of electromagnets, thermal devices or peculiar electro phenomena accomplishes the function of regulation

of the action of the particular devices. For example, the voltage delivered by a generator may be regulated to remain constant irrespective of load by various methods of automatic regulation. Or the current from a transformer may be maintained constant by automatic regulation due to inherent electromagnetic reaction.

Battery, Electric.—A term correctly expressing the fact that several electric cells are so connected that they all contribute energy to the external circuit.

Bolometer.—A delicate piece of apparatus used to measure minute changes in temperature. Its principle of operation is the measurement of the resistance variation of a hairlike piece of platinum wire under the influence of the heat in question.

Brush Discharge.—A faint bluish discharge that occurs from pointed projections of a conducting system under abnormal voltage strain.

Brushes of a Dynamo-electric Machine.—Blocks of carbon or copper gauze or strips used to bear upon a revolving member—either commutators or slip rings—to lead current into and from such a member.

Calibration.—Comparison of a certain meter—such as an ammeter, voltmeter, etc.—with a standard meter in order to determine the amount of error of the meter under test.

Capacity.—The ability of a system of electric conductors to store up electrical energy. The device employed for this purpose is called a condenser. It is extensively employed in telegraph, telephone, and radio communication systems.

Cathode.—The plate of a battery from which electricity flows into the external circuit. It is the positive terminal of the battery.

Cell.—A combination of metal plates immersed in a liquid called the electrolyte which is capable of supplying an electric current to an external circuit. It is one element of a battery. There are many kinds of cells employing different kinds of metals, different types of electrolytes, and giving widely variant voltages. Primary cells give an electric current until the electrodes are consumed. They are then useless until the old electrodes are renewed. Secondary cells are most commonly called storage cells which must first be charged before they become capable of giving off electric energy.

Charge, Electric.—A quantity of electricity that resides on the surface of an insulated electrified conductor. Charges are of two kinds—positive charge and negative charge. The electron theory accounts for these two types as being atoms with less or more negative electrons respectively than positive electrons. If an atom has as many negative electrons revolving about the center nucleus as there are positive charges in the nucleus, then the atom is said to be a neutral atom.

Circuit, Electric.—A conductive path for the flow of an electric current. Open circuit is one in which the circuit conducting continuity is disturbed. Closed circuit is one in which the conducting continuity is complete. External circuit indicates a path by which electricity flows from the source through apparatus and back into the source. The circuit through the source itself is often called the internal circuit. Grounded circuit is one in which the ground forms a part of the conducting system.

Circuit, Magnetic.—A path by which magnetic lines of force may pass. All lines form closed circuits and follow the path of least resistance in their passage. Magnetic materials constitute low resistance paths for such lines of force, whereas air offers a very high resistance.

Circuit, Series.—Where the current has but one path throughout. The apparatus in a series circuit is joined in tandem so that the current which flows through one device also flows through each of the others in tandem. When batteries are connected in series, the voltage is the sum of the individual cells.

Circuit, Shunt.—A circuit which forms an additional path for the flow of an electric current.

Coil, Induction.—The induction coil as commonly meant by this term is an electric and magnetic system whereby a low direct current voltage is converted into a high alternating current voltage. There is a primary circuit having a few turns of heavy wire wound upon an iron core in which circuit is connected a battery and an interrupter. As the interrupter rapidly makes and breaks the primary circuit current, the lines of force of this current expanding and collapsing in accordance therewith induces a voltage in the secondary winding of an alternating nature. This secondary coil is constituted of many turns of fine wire wound directly over the primary coil. Such coils are extensively used in medical and X-ray work, gas engine ignition systems and for experimental purposes.

Coil, Resistance.—A coil of wire of known resistance usually employed in measuring instruments for determining unknown values of resistance. Such coils are almost universally made of manganin, an alloy material for which the resistance has no change with temperature fluctuations.

Commutator.—From the Latin root, *commuto*, the word means to change. As employed in the electrical sense, it means a device employed for changing the direction of an electric current. It is a distinguishing feature of all direct current motors and generators. The current in the armature of such a machine is fundamentally alternating, but by virtue of a commutator it changes it to direct current in the external circuit. A commutator may always be distinguished on a dynamo as a copper cylinder mounted coaxial with the shaft and slotted into segments axially, these

segments being insulated from each other and the shaft by mica.

Compass.—A device having a magnetized needle mounted upon a pivot which always points toward the magnetic poles. The mariner's compass is especially well constructed and employed on shipboard for the guidance of the pilot.

Condenser.—A device extensively employed in electrical circuits and composed of sheets of metal which are separated by a good insulator of electricity. Very good condensers are made by using thin plates of copper or lead foil separated by glass, mica, paraffin paper, or air. If more than two plates are employed, alternate ones are connected to one terminal and the intermediate ones to the other terminal.

Conduit.—A space for the reception of electric wires or cables.

Converter, Mercury Arc.—A device employing mercury vapor as a means of changing alternating into direct current. Electricity will pass easily only in one direction through the mercury vapor contained in a glass bulb from one electrode to the other. They are used most commonly in storage battery charging plants and with motion picture outfits.

Converter, Rotary.—A rotating dynamo-electric machine extensively employed in traction systems for changing alternating current which is received in a substation to direct current for use in propelling the trolley cars, electric trains, and locomotives.

Core.—As applied to electrical machinery, a core is most usually an iron construction, frequently of iron laminations placed together like the pages of a book, upon which is wound coils of wire. The core in such cases forms an easy path for the lines of force.

Coulomb.—The unit of quantity of electricity as the gallon is the quantity of water. It is named in honor of a great French scientist. A coulomb is the amount of electricity that would result from one ampere flowing for one second.

Counter-Electromotive Force.—Abbreviated as C. E. M. F. —a voltage that is produced in a circuit in the reverse direction to that of the source and tends to make a current flow in the direction opposite from that of the source. Therefore, it acts to reduce the amount of current that flows in a circuit as does a resistance.

Current, Alternating.—See *Alternating Current.*

Current, Direct.—A current that constantly flows in one direction.

Current, Eddy.—A current flow set up in the cores of electric machinery because of variations in the number of lines of force threading such cores. These currents are not only useless so far as the operation of the machine is con-

cerned, but actually a detriment as they heat the irons and cause a loss of energy. By making the core of thin sheets of iron or steel placed across the line of flow of the eddy currents they are very largely reduced.

Current, Electric.—According to the most recent and approved views of electricity, an electric current is the massed movement of electrons—minute particles of electricity that compose a substance. However, it is considered to be only the free electrons that enter into this movement. The free electrons are not directly associated with atoms but are more like wanderers on the face of the earth who are free to go with the tides of desire. These electrons move under the impelling force of a voltage. If the force is increased the quantity of electrons moved is thereby increased.

Demagnetization.—A process whereby the magnetism of a piece of magnetized material is rendered ineffective. For example, a magnet may be demagnetized by heating it to a dull red heat, by violently jarring it or by placing it in a powerful magnetic field in a direction tending to magnetize it in the reverse direction.

Depolarization.—The process of removing the polarizing characteristic of an electric cell.

Dielectric.—A substance which has excellent electrical insulating qualities and permits induction to take place through it. Dielectric materials are placed between the plates of electric condensers.

Dielectric Strain.—When a condenser is charged by impressing upon it a high voltage, the dielectric becomes strained just as a heavy weight placed upon a piece of wood strains it. And just as a too heavy weight on the wood will fracture or crush it, so will too high a voltage cause so great a strain that the dielectric will be broken. That is, a piece of glass placed between the plates of metal may by the application of a high potential difference be broken into a myriad of pieces.

Difference of Potential.—A portion of electromotive force that exists between two points of an electric circuit.

Discharge, Electric.—The equalization of the potential difference that exists because of the flow of electricity from one place to another. A charged condenser, for example, has a difference of potential across its plates and a wire when connected from one terminal to the other equalizes the difference of potential and, therefore, discharges the condenser. A discharge may be conductive, convective, or disruptive, depending upon whether the charged body is discharged by means of a conductor in contact therewith, or by means of the air about the body being electrified and therefore convection currents carrying away the electricity, or lastly by rupturing the dielectric and causing the equalization of charges to occur. This latter is the case of the common lightning strokes.

Dynamic Electricity.—A term occasionally used to denote a current of electricity.

Dynamo-Electric Machine.—A machine that is used to convert mechanical into electrical energy is a dynamo-electric machine and is called a generator. Also a machine for converting electrical into mechanical energy is classified as a dynamo-electric machine and is more specifically designated as a motor. All such machines have in common the following general parts: armature; magnetic circuit—usually the frame being a part; field coil system; and bearings. There are many minor parts which differ in nature with the many various types of machines.

Dynamometer.—A term applied to an electrical device used to measure the power output of an engine or motor.

Efficiency of any machine—either electrical or mechanical.—The ratio of the output of the machine to the input, both expressed in the same units, is called the efficiency. If this ratio is multiplied by 100, it is called per cent efficiency. No machine has yet been constructed in which there are no internal losses thereby giving a 100 per cent efficiency, although electric transformers have reached a degree of perfection giving higher than 99 per cent.

Electricity.—A name given to an unknown substance or force which gives rise to the electrical phenomena with which we are more or less familiar.

Electrode.—A plate, rod or part of an electric circuit which is conspicuous in the proper functioning of the apparatus. The plates of electric cells are electrodes. The metallic plates of an arc-rectifier are called the electrodes. One is usually called the anode and the other the cathode.

Electrolysis.—A name given to an action whereby chemical decomposition results in the change of the material. It is broken up into negative and positive particles called *ions*. The electrolysis is caused by the passage of an electric current. A vessel in which the electrolysis action results is called an electrolytic cell.

Electromagnet.—A magnet produced by the flow of an electric current through a coil of wire. The coil usually has an iron core. Powerful magnets are in this way made capable of lifting many tons of scrap iron and steel. On the other hand magnets of minute size are made which in great numbers may combine to give almost human complication of action.

Electron.—The smallest known division of matter. The electron is the tiny particle of electricity which is the fundamental element of which all material things are made. The electrons in various numbers and configurations constitute the atoms of the eighty-three elements of the universe. These many elements in turn combine according to an almost infinite number of formulæ or recipes to form the myriads of different kinds of matter so familiar to us.

Electro-Therapeutics.—The use of electricity in curing disease.

Energy.—The power of doing work. It is of two kinds: potential and kinetic. Potential energy is that due to the advantage of position; that is, a weight when lifted above the ground becomes able to do an equal amount of work by virtue of its position. Kinetic energy is that due to the momentum of mass. A rolling freight car is capable of doing work as its speed is suddenly checked.

Energy, Electrical.—Electricity possesses the ability to perform work through its many means of application.

Ether.—A highly elastic, tenuous indefinable fluid that is assumed to fill all space. By the vibrations set up in it, light, heat, and electromagnetic waves are transmitted. It is not correct to assume that ether has no weight, since physical proof is fairly conclusive of the affirmative. The subject of ether constitution figures centrally at present in such subjects as Einstein's Relativity Theory.

Farad.—The unit of electrical capacity. A condenser is said to have a capacity of one farad when a charge of one coulomb of electricity raises the potential difference at the terminals by one volt. The farad is such an enormous quantity that for practical work a millionth part of it called the *microfarad* is in common usage.

Field.—There are two types of fields found in electrical work—the one called the electrostatic field and the other the magnetic field.

The electrostatic field is force influence surrounding an electrified body. That is, for example, the space between the plates of a condenser is in a peculiar state of strain due to the electrostatic influence—so great may this field strength become that it may shatter a piece of glass or hard rubber placed between the plates.

The magnetic field is that influence surrounding the magnetic substance or a coil being traversed by a current that causes pieces of magnetic materials such as iron, steel, nickel, and cobalt to be attracted to it. The environment of the magnet is under a strain which may become so great that tons of weight may be held suspended by this invisible bond of mystery.

Field Strength.—A measure of the force of the field. Usually the number of lines of force per square inch or per square centimeter signifies the field intensity.

Foot-Candle.—A unit of intensity of illumination. It is the intensity of illumination produced by a standard source of one candle at a distance of one foot. For comfortable reading the page should have not less than three foot-candles intensity. Drafting work requires from seven to ten foot-candles.

Force, Magnetic.—It is the force that causes bodies of magnetic material to be attracted or repelled by the poles of a magnet.

Fuse, Safety.—A strip of alloy metal so proportioned that it melts when the current reaches a predetermined value and thereby opens the circuit. Fuses are found in link form, inclosed in a fiber container with ferrule clips or blade clips, or they may be inclosed in a porcelain cup with an Edison screw base. They are always included in lighting circuits.

Galvanic Battery.—Two or more voltaic cells arranged so as to form one source of energy.

Galvanometer.—An instrument used to measure or detect minute values of current.

Generator.—A machine whereby electromotive force is produced by the relative movement of conductors and a magnetic field. They may produce either alternating or direct current voltage.

Ground Wire or Plate.—A wire that connects from one side of an electric system and runs down into the ground is called a ground wire. Such a system is said to be grounded. A ground plate is usually a large plate buried deeply into the ground and surrounded by a layer of charcoal so that good moist contact always results. A ground wire should connect to a ground plate for best results. A water or sewer pipe usually forms an excellent ground medium.

Heat Unit.—The calorie is the most commonly employed heat unit. It is defined as the amount of heat required to raise one gram of water through one degree centigrade. This is a small calorie. If the weight is 1,000 grams or 2.2 pounds of water, the unit is the large calorie. The joule is sometimes employed and is 0.24 of a calorie. A joule of heat is liberated when one ampere passes through one ohm of resistance.

Horsepower.—This is a unit of power in commercial use. It is the rate of work equal to doing 33,000 foot-pounds per minute. Raising a weight through a distance is work; but when the time rate enters it is then power. Only a small power is required relatively to lift the weight slowly; but the very rapid raising requires a high power. The use of a freight and express elevator presents excellent examples of this difference.

Ignition, Electric.—An electric spark is most commonly employed to ignite charges of compressed gases—such as those in gasoline engines. The spark may be caused by a high voltage arcking across the tips of a spark plug or it may be caused by the breaking of the electric circuit by a moving contact. The former is exclusively in vogue on automobile engines, while the latter is extensively used for stationary gas engines.

Induced Electromotive Force.—A voltage that is caused by the expansion or contraction of a magnetic field across turns of wire is said to be an induced voltage. It is in contradistinction to a generated voltage in which case the conductors do the moving rather than the magnetic field.

Induction, Electrodynamic.—Electromotive forces produced by the variations or cutting of a magnetic field across a coil or conductors or wire are called induced E. M. F.'s. The actions of the various forms of induction coils and of transformers are dependent upon this principle. There are an enormous number of applications of the principle some of which are useful and others that cause undesirable disturbances in electric systems.

There is also electrostatic induction in which a charge may be induced on another body by being merely in the vicinity of the inducing charge. A charge acquired in this way is called an induced charge.

Inertia.—That property—the distinguishing characteristic of mass—by which it tends to remain in a state of motion in a straight line or in a state of rest unless it is acted upon by extraneous forces to change this condition. The principle of inertia is Newton's first law of motion.

Insulators.—Devices employed to keep electric currents from taking other circuits than those prescribed by circuits designed by the engineers. For exterior running of wires, insulators are generally in the form of glass or porcelain holders used to keep the wires in place on crossarms. For interior work, the wire is insulated by a covering that serves as an insulating medium. Many forms of oiled silks, varnished cambrics, paper, mica, etc., are used in various types of insulating demands and are called *insulating materials.*

Intensity of Current.—A term used to indicate the strength of an electric current.

Intensity of Field.—The strength of a magnetic or electrostatic field is usually measured by the number of lines of force per square inch or per square centimeter of area taken at right angles to their direction.

Ions.—Groups of atoms having negative and positive characteristics by virtue of electrolytic decomposition of a molecule when the atom has lost one or more electrons, the preponderance of positive electricity makes it positive in nature. The acquisition of one or more electrons to an atom gives it a preponderance of negative electricity since the electrons are negative particles of electricity.

Joule.—The unit of electrical energy equivalent to 0.24 of a calorie. It is equal to one watt-second; that is, one ampere flowing through one ohm of resistance for one second.

Kilowatt.—The prefix kilo means one thousand times. Therefore kilowatts would mean one thousand watts. It is a very common unit in electrical measurement.

Lamination.—Steel and iron cores are usually not made of solid material but rather of thin sheets or plates of the material and held together by clamps, bolts or other means. This method reduces the harmful eddy current losses to a minimum.

Leakage of Electricity.—The gradual dissipation of a charge or current due to insufficient insulation. This leakage can in general be obviated by the use of proper insulation.

Leakage, Magnetic.—Failure of magnetic lines of force to pass through the particular part of the circuit where they are required. Since there is no known means of insulating the effect of magnetism, some leakage cannot be eliminated. By proper design it is reduced to as low a value as possible. Lines of force that are useless in performing the function required of them are said to be leakage lines or stray field. Such magnetic leakage results in inefficiency and poor operation of machinery.

Lenz's Law of Induction.—The direction of the current produced by electromagnetic induction is in a direction that always opposes any change in the current strength of the inducing system.

Light, Electromagnetic Theory of.—This theory was advanced by Clerk Maxwell in his epochal mathematical works. It is now considered to be true. The phenomena of heat, light, electromagnetic radiation and magnetism are all explainable by the same means. Light and heat are produced by the to and fro movement of the electrons acting as little pistons pulsating the ether and causing waves of different length and complex nature to be radiated. Electric and magnetic influence is attributable to the circular motion of electrons in their orbits. Certain wave lengths of the ether affect the optic nerve and are interpreted as light. Waves of longer length are called radiant heat waves or infra-red spectra, while still longer waves are designated as electromagnetic waves.

Lightning.—An electric discharge from cloud to cloud or from cloud to earth.

Lightning Arrester.—A device by means of which equipment associated with an electric circuit may be protected from destructive effects of the lightning.

Lightning Rods.—Iron rods or cables that are connected from the ground up the exterior side of buildings and terminate in sharp, forked ends a few feet above the highest part of the roof for the purpose of discharging quietly before a flash occurs the electrical energy of the charge. They serve in this way as a protection against direct strokes and consequent fire hazard.

Line of Force.—A line of force is the line that shows at every successive position the direction of the line of action of any force, be it electric, magnetic, or static.

Loadstone.—A name given to a piece of iron which has the magnetic property and can hold small pieces of iron or steel in suspension.

Local Action.—See *Action.*

Machine, Influence.—A machine that by revolution causes an increasing charge to accumulate in a condenser. This charge can be discharged across an air gap and oscillations of high frequency produced. It is used extensively in electrotherapeutics and for experimental purposes. It is the process of influence whereby a small charge is increased by increments until a large charge is obtained.

Magnet.—There are two general types of magnets: one called the artificial and the other the natural. The artificial type is further subdivided into permanent and electromagnets. The natural magnet is the loadstone—a black, heavy rock containing iron compounds capable of attracting small pieces of magnetic material.

The permanent artificial magnet is made of steel and so treated that it has the property of attracting bits of iron or steel. Such magnets are made in various shapes—two most common forms being the straight bar magnet and the horseshoe-shaped magnet. The electromagnet is so named because the passage of an electric current through a wire causes magnetic attraction as does the permanent magnet. The presence of an iron core through a helical coil of wire can be made to have a powerful lifting effect when the coil is energized by the flow of an electric current.

Magnetic Field.—See *Field.*

Magnetic Permeability.—That characteristic of a substance which is a measure of the ease with which lines of force pass through it. Some substances have higher permeability than others, meaning that lines of force more readily pass through them. It is the opposite of magnetic reluctance which is the difficulty offered to the flow of lines of force.

Magnetic, Residual.—When a piece of iron or steel has been once magnetized it retains a certain amount of its magnetism after the magnetizing force has been removed, this remaining magnetism is said to be remanent or residual.

Magnetic Saturation.—The force that magnetizes a substance is increasingly applied until a condition is reached where increased application of magnetic force fails to increase the resulting magnetic strength. This condition is called magnetic saturation.

Magnetic Storms.—Sudden variations in the distribution of the magnetic force over the earth's surface. They are affected by auroral displays, sun spots, and outbursts of solar activity.

Magnetism.—This term is used as a synonym for magnetic field.

Mains, Electric.—The principal conductors in any electrical system of power distribution.

Mil.—A unit used in the measurement of wire. It is 1/1000th part of an inch.

Mil, Circular.—A conventional area used in the designation of wire sizes. It is 0.7854 square mil. A round wire has its circular mil area determined by squaring its diameter expressed in mils.

Motor, Electric.—A machine employed to convert electrical energy into mechanical energy. There is a vast variety of such motors for use on either direct or alternating current.

Mover, Prime.—A prime mover is the driving unit that causes the other pieces of machinery to be driven. For example, a steam engine is a prime mover driving a generator or a pump. A motor driving other machines is also a prime mover.

Multiplex Telegraphy.—A telegraphic system in which more than four messages can be transmitted over one wire either all in one direction or partly in one and the remainder in the other direction simultaneously.

Network.—A term frequently used to indicate a number of shunt circuits in a distribution system.

Neutral Points.—In a generator, a pair of points at the ends of a diameter through a commutator where the collecting brushes are placed are called the neutral points. The greatest electromotive force is there available.

Nonconductors.—Insulating materials in the electrical terminology are nonconductors. They offer a very high resistance to the flow of a current.

Ohm.—This is the unit of resistance. A resistance of one ohm would limit the flow of an electric current to one ampere under a pressure of one volt.

Ohmic Resistance.—A term sometimes used to denote that the resistance is due only to the dimensions and quality of the conductor and not to the effect of a counterelectromotive force.

Ohm's Law.—"The strength of the current in any circuit is directly proportional to the difference of potential, or electromotive force in that circuit, and inversely proportional to the resistance of the circuit, i. e., is equal to the quotient arising from dividing the electromotive force by the resistance." The algebraic expression of the law is:

$$i = \frac{E}{R}$$

The current (i) is given in amperes, the electromotive force (E) in volts, and the resistance (R) in ohms.

Oscillations, Electric.—The rapid transversals of electric charge in a system are called electric oscillations. The dis-

charge of a condenser through a very low resistance would produce an oscillatory flow of current. The condenser in discharging would overdischarge because of the low resistance just as a pendulum bob in air would swing beyond the lowest point due to its inertia and lack of resistance. A lightning stroke from cloud to cloud or cloud to earth consists of an oscillatory current of millions of cycles per second.

Permanent Magnet.—See *Magnet.*

Permeability, Magnetic.—See *Magnetic Permeability.*

Photometer.—A device for measuring the intensity of the light emitted by any luminous source. There are a vast number of different types, but in the usual types the unknown source is compared with a standard unit of illumination.

Plating, Electro.—The depositing or plating of one metal on another by the action of an electric current.

Polarity, Magnetic.—A piece of magnetic material when brought into the influence of magnetism acquires definite polarity—a north pole where the lines of force leave the substance and a south pole where they enter.

Pole Pieces of Dynamos.—Masses of soft iron forming a part of the magnetic circuit which conform to the cylindrical shape of the armature. The armature revolves within the pole pieces so as to cut the lines of force and thereby produce an electromotive force.

Potential, Electric.—Electric level is a synonymous term. The power of doing electric work. Potential in this sense means pressure as the weight of water causes a pressure at the bottom of a tank capable of forcing it through a hose or a water wheel, so can electric potential cause a current of electricity to flow along a wire and make a motor revolve. In the case of water, a pump causes the difference of level or pressure by storing the water in a reservoir, whereas in electrodynamics, a dynamo causes a difference of potential by the conductors cutting a field of magnetic force.

Quantity, Unit of Electric.—The unit of electrical quantity is the coulomb. A current of one ampere flowing for one second means that a quantity of electricity of one coulomb has been transferred along the wire.

Relay.—A relay is a delicate electromagnet device placed in the line of a system to be actuated by the line current to close circuits that will operate more heavy or powerful devices. For example, telegraph relays are connected in the main lines and operate upon a very minute current, which in turn operate the heavier sounders through a local circuit and thereby make very loud the feeble signals of the relay. There are a vast variety of relays that are parts of different kinds of machines and circuits.

Resistance, Electrical.—The ratio between the electromotive force and current that passes through it. It is a molec-

ular condition of the circuit and varies with different materials. The resistance opposes the flow of the current. The measurement of resistance is accomplished by comparison with certain standards that are made from high quality materials to insure permanency of value.

Rheostat.—A device placed in the circuit having variable resistance in order that easy control of the current flow may be had.

Saturation, Magnetic.—See *Magnetic Saturation.*

Self-Induction.—The induction of an electromotive force in the same circuit that produces the inducing influence. That is, for example, a varying current in traversing a coil of wire induces an electromotive force therein which opposes the active or impressed potential. This is called a self-induced electromotive force.

Series Circuit.—A type of connection of apparatus in which the current flows through the devices in succession. It is a tandem connection of the equipment.

Short Circuit.—A shunt or by-pass circuit of very low resistance, which is usually accompanied by dangerously high current flow. The use of fuses obviates danger from short circuits as they burn and thereby open the circuit.

Solenoid.—This is a name given to a helical coil of wire. It may or may not have an iron core. It is very common in electrical devices.

Sounder.—As applied to the electrical field a sounder is a device to amplify the feeble signals of the line relays on a telegraph circuit. It is an electromagnet connected through the armature of the line relay and a local battery so that as the relay armature is opened and closed corresponding to the dots and dashes transmitted causes the heavy armature of the sounder to respond in a similar manner but with amplified sound.

Sparking of Dynamo-electric Machines.—An injurious arcking at the commutator with the brushes causing a burning and heating of the commutator resulting in severe harm to the machine. Sometimes it is caused by a rough, uneven and dirty commutator, by poorly fitting brushes, or by wrong position of the brush axis.

Static Electricity.—This term means as now used static charge, which is an accumulation of either positive or negative electricity.

Storage Cell.—An electric cell that may be charged by the passage of an electric current through it causing certain chemical reactions which are reversible upon discharge as the cell is being used. This means that the cell can be used over and over again. There are two general types—one called the lead cell and the other the nickel-iron cell or Edison cell.

Synchronism.—The simultaneous occurrence of any two or more events.

Telegraph, Electric.—A system or electrical apparatus whereby signals of communication can be transmitted from one station to another over a wire circuit. The system is composed of: (1) Transmitting apparatus to give electrical impulses to the line; (2) Receiving apparatus by means of which these impulses may be made to give audible or visible signals; (3) The conducting lines; (4) Energizing battery system used to produce the electrical energy; and (5) Relays and repeaters inserted in the line wherever a station is desired.

Telegraphy, Duplex.—This system permits the transmission of two simultaneous messages over the line in opposite directions without interference.

Telephony.—A system whereby articulate speech may be electrically transmitted over a conducting system. It consists: (1) of a transmitting equipment by means of which the voice waves are changed into electrical impulses of complex character; (2) of a receiving apparatus whose function it is to reconvert the electrical impulses into voice waves; (3) the conducting medium for the electric currents; and (4) the central office switching equipment for interconnecting any subscriber.

Thermoelectricity.—Electricity produced by differences of temperature at the junction of dissimilar metals—bismuth and antimony giving the greatest electromotive force. This principle is used extensively in measuring flue temperature and also for minute differences of temperature.

Vacuum, High.—A space from which nearly all residual gas has been removed.

Volt.—The practical unit of electromotive force. One volt of pressure makes one ampere flow through a resistance of one ohm.

Voltmeter.—A meter that reads directly the electromotive force in that part of the circuit under measurement.

Watt.—A unit of electrical power. It is the product of volts and amperes; 746 watts equal one horsepower.

Wattmeter.—An instrument used to record the power consumed in a circuit.

TABULAR INFORMATION ON ELECTRICAL CONDUCTORS

TABLE I

COMPLETE STANDARD ANNEALED COPPER WIRE TABLE

AMERICAN WIRE GAUGE (B. & S.). ENGLISH UNITS

Gauge No.	Diameter in Mils at 20° C.	Pounds per 1,000 ft.	Feet per Pound	Feet per ohm	
				20° C (=68° F.)	50° C (=122° F.)
0000	460.0	640.5	1.561	20,400.0	18,250.0
000	409.6	507.9	1.968	16,180.0	14,470.0
00	364.8	402.8	2.482	12,830.0	11,480.0
0	324.9	319.5	3.130	10,180.0	9,103.0
1	289.3	253.3	3.947	8,070.0	7,219.0
2	257.6	200.9	4.977	6,400.0	5,725.0
3	229.4	159.3	6.276	5,075.0	4,540.0
4	204.3	126.4	7.914	4,025.0	3,600.0
5	181.9	100.2	9.980	3,192.0	2,855.0
6	162.0	79.46	12.58	2,531.0	2,264.0
7	144.3	63.02	15.87	2,007.0	1,796.0
8	128.5	49.98	20.01	1,592.0	1,424.0
9	114.4	39.63	25.23	1,262.0	1,129.0
10	101.9	31.43	31.82	1,001.0	895.6
11	90.74	24.92	40.12	794.0	710.2
12	80.81	19.77	50.59	629.6	563.2
13	71.96	15.68	63.80	499.3	446.7
14	64.08	12.43	80.44	396.0	354.2
15	57.07	9.858	101.4	314.0	280.9
16	50.82	7.818	127.9	249.0	222.8
17	45.26	6.200	161.3	197.5	176.7
18	40.30	4.917	203.4	156.6	140.1
19	35.89	3.899	256.5	124.2	111.1
20	31.96	3.092	323.4	98.50	88.11
21	28.46	2.452	407.8	78.11	69.87
22	25.35	1.945	514.2	61.95	55.41
23	22.57	1.542	648.4	49.13	43.94
24	20.10	1.223	817.7	38.96	34.85
25	17.90	0.9699	1,031.0	30.90	27.64
26	15.94	0.7692	1,300.0	24.50	21.92
27	14.20	0.6100	1,639.0	19.43	17.38
28	12.64	0.4837	2,067.0	15.41	13.78
29	11.26	0.3836	2,607.0	12.22	10.93
30	10.03	0.3042	3,287.0	9.691	8.669
31	8.928	0.2413	4,145.0	7.685	6.875
32	7.950	0.1913	5,227.0	6.095	5.452
33	7.080	0.1517	6,591.0	4.833	4.323
34	6.305	0.1203	8,310.0	3.833	3.427
35	5.615	0.09542	10,480.0	3.040	2.719
36	5.000	0.07568	13,210.0	2.411	2.156
37	4.453	0.06001	16,660.0	1.912	1,710
38	3.965	0.04759	21,010.0	1.516	1.356
39	3.531	0.03774	26,500.0	1.202	1.075
40	3.145	0.02993	33,410.0	0.9534	0.8529

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TABLE II

COMPLETE STANDARD ANNEALED COPPER WIRE TABLE—*Continued*

AMERICAN WIRE GAUGE (B. & S.). ENGLISH UNITS

Gauge No.	Diameter in Mils at 20° C.	Cross Section at 20° C.		Ohms per 1,000 ft.	
		Circular Mils	Square Inches	20° C. (=68° F.)	50° C. (=122° F.)
0000	460.0	211,600.0	0.1662	0.04901	0.05479
000	409.6	167,800.0	0.1318	0.06180	0.06909
00	364.8	133,100.0	0.1045	0.07793	0.08712
0	324.9	105,500.0	0.0829	0.09827	0.1099
1	289.3	83,690.0	0.06573	0.1239	0.1385
2	257.6	66,370.0	0.05213	0.1563	0.1747
3	229.4	52,640.0	0.04134	0.1970	0.2203
4	204.3	41,740.0	0.03278	0.2485	0.2778
5	181.9	33,100.0	0.02600	0.3133	0.3502
6	162.0	26,250.0	0.02062	0.3951	0.4416
7	144.3	20,820.0	0.01635	0.4982	0.5569
8	128.5	16,510.0	0.01297	0.6282	0.7023
9	114.4	13,090.0	0.01028	0.7921	0.8855
10	101.9	10,380.0	0.00815	0.9989	1.117
11	90.74	8,234.0	0.006467	1.260	1.408
12	80.81	6,530.0	0.005129	1.588	1.775
13	71.96	5,178.0	0.004067	2.003	2.293
14	64.08	4,107.0	0.003225	2.525	2.823
15	57.07	3,257.0	0.002558	3.184	3.560
16	50.82	2,583.0	0.002028	4.016	4.489
17	45.26	2,048.0	0.001609	5.064	5.660
18	40.30	1,624.0	0.001276	6.385	7.138
19	35.89	1,288.0	0.001012	8.051	9.001
20	31.96	1,022.0	0.0008023	10.15	11.35
21	28.46	810.1	0.0006363	12.80	14.31
22	25.35	642.4	0.0005046	16.14	18.05
23	22.57	509.5	0.0004002	20.36	22.76
24	20.10	404.0	0.0003173	25.67	28.70
25	17.80	320.4	0.0002517	32.37	36.18
26	15.94	254.1	0.0001996	40.81	45.63
27	14.20	201.5	0.0001583	51.47	57.53
28	12.64	159.8	0.0001255	64.90	72.55
29	11.26	126.7	0.00009953	81.83	91.48
30	10.03	100.5	0.00007894	103.2	115.4
31	8.928	79.70	0.00006260	130.1	145.5
32	7.950	63.21	0.00004964	164.1	183.4
33	7.080	50.13	0.00003937	206.9	231.3
34	6.305	39.75	0.00003122	260.9	291.7
35	5.615	31.52	0.00002476	329.0	367.8
36	5.000	25.00	0.00001964	414.8	463.7
37	4.453	19.83	0.00001557	523.1	584.8
38	3.965	15.72	0.00001235	659.6	737.4
39	3.531	12.47	0.000009793	831.8	929.8
40	3.145	9.888	0.000007766	1,049.0	1,173.0

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TABLE III

COMPLETE STANDARD ANNEALED COPPER WIRE TABLE—*Continued*

AMERICAN WIRE GAUGE (B. & S.). ENGLISH UNITS

Gauge No.	Pounds per Mile	Ohms per Mile		Pounds per Ohm	
		25° C. (=77° F.)	65° C. (=149° F.)	20° C. (=68° F.)	50° C. (=122° F)
0000	3,380	0.264	0.305	13,070.0	11,690.0
000	2,680	0.333	0.384	8,219.0	7,352.0
00	2,130	0.420	0.484	5,169.0	4,624.0
0	1,680	0.528	0.613	3,251.0	2,908.0
1	1,340	0.665	0.771	2,044.0	1,829.0
2	1,060	0.840	0.972	1,286.0	1,150.0
3	840	1.06	1.23	808.6	723.3
4	665	1.34	1.54	508.5	454.9
5	528	1.68	1.95	319.8	286.1
6	420	2.13	2.46	201.1	179.9
7	333	2.68	3.09	126.5	113.2
8	264	3.38	3.90	79.55	71.16
9	209	4.27	4.92	50.03	44.75
10	166	5.39	6.23	31.47	28.15
11	132	6.76	7.81	19.79	17.70
12	105	8.55	9.87	12.45	11.13
13	82.9	10.8	12.5	7.827	7.001
14	65.5	13.6	15.7	4.922	4 403
15	52.1	17.2	19.8	3.096	2.769
16	41.3	21.6	25.0	1.947	1.742
17	32.7	27.2	31.5	1,224	1.095
18	26.0	34.4	39.7	0.770	0.6888
19	20.6	43.4	50.1	0.4843	0.4332
20	16.3	54.9	62.8	0.3046	0.2725
21	12.9	69.2	79.7	0.1915	0.1713
22	10.24	87.1	100	0.1205	0.1078
23	8.13	110	127	0.07576	0.06777
24	6.44	138	159	0.04765	0.04262
25	5.12	174	201	0.02997	0.02680
26	4.06	220	253	0.01885	0.01686
27	3.22	277	320	0.01185	0.01060
28	2.56	350	403	0.007454	0.006668
29	2.03	440	509	0.004688	0.004193
30	1.61	554	639	0.002948	0.002637
31	1.27	702	808	0.001854	0.001659
32	1.01	882	1,020	0.001166	0.001043
33	0.803	1,110	1,280	0.0007333	0.0006560
34	0.634	1,400	1,620	0.0004612	0.0004126
35	0.504	1,770	2,040	0.0002901	0.0002595
36	0.400	2,230	2,580	0.0001824	0.0001632
37	0.317	2,810	3,250	0.0001147	0.0001026
38	0.251	3,550	4,100	0.00007215	0.00006454
39	0.199	4,480	5,170	0.00004538	0.00004059
40	0.158	5,650	6,490	0.00002854	0.00002553

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TABLE IV

ALLOWABLE OR SAFE CURRENT CARRYING CAPACITIES OF INSULATED COPPER WIRES

(National Electric Code)

Circular Mils	A. W. G.	Table A Rubber Insulation (Amps.)	Table B Other Insulation (Amps.)	Circular Mils	A. W. G.	Table A Rubber Insulation (Amps.)	Table B Other Insulation (Amps.)
1,624	18	3	5	200,000		200	300
2,583	16	6	10	300,000		275	400
4,107	14	15	20	400,000		325	500
6,530	12	20	25	500,000		400	600
10,380	10	25	30	600,000		450	680
16,510	8	35	50	700,000		500	760
26,250	6	50	70	800,000		550	840
33,100	5	55	80	900,000		600	920
41,740	4	70	90	1,000,000		650	1,000
52,630	3	80	100	1,100,000		690	1,080
66,370	2	90	125	1,200,000		730	1,150
83,690	1	100	150	1,300,000		770	1,220
105,500	0	125	200	1,400,000		810	1,290
133,000	00	150	225	1,500,000		850	1,360
167,800	000	175	275	1,600,000		890	1,430
211,600	0000	225	325	1,700,000		930	1,490
				1,800,000		970	1,550
				1,900,000		1,010	1,610
				2,000,000		1,050	1,670

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TABLE V

ENERGY

	Ergs	Reciprocal	Gram-wt-cm. g=980.7	Reciprocal	Gram-calories	Reciprocal
1 Erg	1	1	1.0197×10^{-3}	980.7	0.2389×10^{-7}	4.186×10^{7}
1 Joule	10^{7}	10^{-7}	1.0197×10^{4}	0.9807×10^{-4}	0.2389	4.186
1 Gram-wt-cm (g=980.7)	980.7	1.0197×10^{-3}	1	1.0	0.2342×10^{-4}	4.269×10^{4}
1 Gram-calorie	4.186×10^{7}	0.2389×10^{-7}	4.269×10^{4}	0.2342×10^{-4}	1.0	1.0
1 Kilogram-calorie	4.186×10^{10}	0.2389×10^{-10}	4.269×10^{7}	0.2342×10^{-7}	1000	10^{-3}
1 foot-gram (g=980.7)	1.937×10^{3}	0.5163×10^{-3}	1.975	0.5063	0.4628×10^{-4}	2.161×10^{4}
1 foot-pound (g=980.7) *	1.356×10^{7}	0.7375×10^{-7}	1.383×10^{4}	0.7231×10^{-4}	0.3240	3.086
1 foot-long ton (g=980.7)	3.037×10^{10}	0.3293×10^{-10}	3.097×10^{7}	0.3229×10^{-7}	0.7256×10^{3}	1.378×10^{-3}
1 foot-short ton (g=980.7)	2.712×10^{10}	0.3687×10^{-10}	2.766×10^{7}	0.3615×10^{-7}	0.6480×10^{3}	1.543×10^{-3}
1 British thermal unit	1.054×10^{10}	0.9488×10^{-10}	1.075×10^{7}	0.9302×10^{-7}	0.2518×10^{3}	3.971×10^{-3}
1 Watt-hour	3.600×10^{10}	0.2778×10^{-10}	3.671×10^{7}	0.2724×10^{-7}	0.8602×10^{3}	1.163×10^{-3}
1 Kilowatt-hour	3.600×10^{13}	0.2778×10^{-13}	3.671×10^{10}	0.2724×10^{-10}	0.8602×10^{6}	1.163×10^{-6}
1 Horsepower-hour † =(746 Watt-hours)	2.686×10^{13}	0.3723×10^{-13}	2.739×10^{10}	0.3651×10^{-10}	0.6418×10^{6}	1.558×10^{-6}
1 Horsepower-hour (745.7 Watt-hours. g=980.7)	2.684×10^{13}	0.3726×10^{-13}	2.737×10^{10}	0.3654×10^{-10}	0.6412×10^{6}	1.560×10^{-6}
1 Metric horsepower-hour (736 Watt-hours) ‡	2.650×10^{13}	0.3774×10^{-13}	2.702×10^{10}	0.3701×10^{-10}	0.6332×10^{6}	1.579×10^{-6}
1 Metric horsepower-hour (735.5 Watt-hours) (g=980.7)	2.648×10^{13}	0.3776×10^{-13}	2.700×10^{10}	0.3704×10^{-10}	0.6326×10^{6}	1.581×10^{-6}

* For local foot-pound varies between the equator and the poles according to the local intensity of gravitation between the limits 1.352 and 1.359 joules.

† For g=981.2 for approximate latitude of London.

‡ For g=981.3 for approximate latitude of Berlin.

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TABLE VI

THERMOELECTRIC POWERS* IN MICROVOLTS PER DEGREE, AT AN AVERAGE TEMPERATURE OF 20° C.

Substance	Microvolts	Substance	Microvolts
Bismuth	—89	Zinc	+ 3.7
Cobalt	—22	Copper	+ 3.8
German Silver	—12	Iron	+ 17.5
Lead	0	Antimony	+ 24
Silver	+3	Selenium	+807

* The variation of the thermoelectromotive force per degree centigrade is called the thermoelectric power. Lead is the common element in all the above couples.

TABLE OF SPARK POTENTIALS BETWEEN SLIGHTLY CURVED SURFACES IN AIR

Spark Length	Voltage	Voltage per cm.
0.0015 cm	426	284,000
0.01 cm	948	94,800
0.1 cm	4,419	44,190
0.5 cm	16,326	32,652
0.8 cm	25,458	31,822
1.0 cm	31,650	31,650

POTENTIAL OF VARIOUS ELEMENTS

Element	Potential against Hydrogen	Element	Potential against Hydrogen
Manganese	+1.075 volt	Hydrogen	±0.0 volt
Zinc	+0.770 volt	Copper	—0.329 volt
Cadmium	+0.420 volt	Mercury	—0.753 volt
Iron	+0.344 volt	Silver	—0.771 volt
Cobalt	+0.232 volt	Chlorine	—1.353 volt
Nickel	+0.228 volt	Bromine	—0.993 volt
Lead	+0.151 volt	Iodine	—0.520 volt

TABLE VII

Substance	Resistivity	Range of Temperature	Temperature Coefficient of Resistivity
Aluminum	3.09×10^{-6} at 0°C	0°—100°C.	0.00423
Copper	1.59×10^{-6} at 18°C	0°—100°C.	0.00428
Gold	2.17×10^{-6} at 0°C	12°—100°C.	0.00377
Iron (soft)	8.85×10^{-6} at 0°C	0°—100°C.	0.00625
Lead	1.99×10^{-5} at 0°C	0°—100°C.	0.00411
Mercury	9.407×10^{-5} at 0°C	0°— 15°C.	0.000879
Platinum (hard)	1.17×10^{-5} at 0°C	0°—100°C.	0.003669
Platinum (soft)	1.54×10^{-5} at 0°C	0°—100°C.	0.003669
Silver	1.54×10^{-6} at 0°C	0°—100°C.	0.00400
Manganin (Cu 84, Ni 4, Mn 12)	4.76×10^{-5} at 0°C	18°— 50°C.	0.000018
Platinoid (Cu 62, Ni 15, Zn 22)	3.44×10^{-5} at 18°C	18°C.	0.00025
Platinum-silver 85 % Ag-15% Pt	2.26×10^{-5} at 0°C	13°—100°C.	0.000255 (hard) 0.000344 (soft)

Substance	Symbol	Atomic Weight (O=16)	Valency	Electrochemical Equivalent
Aluminum	Al	27.1	3	
Antimony	Sb	120.2	3	
Bismuth	Bi	208.0	3	
Bromine	Br	79.92	1	0.0008284
Cadmium	Cd	112.40	2	
Calcium	Ca	40.7	2	
Chlorine	Cl	35.46	1	0.00003676
Copper	Cu	63.57	1 or 2	0.0003293
Gold	Au	197.2	3	
Hydrogen	H	1.008	1	0.00001044
Iodine	I	126.92	1	
Iron	Fe	55.84	2 or 3	
Lead	Pb	207.10	2	
Mercury	Hg	200.6	1 or 2	
Oxygen	O	16.0	2	0.00008293
Platinum	Pt	195.2	4	
Potassium	K	39.10	1	
Silver	Ag	107.88	1	0.0011183
Sodium	Na	23.00	1	0.0002384
Tin	Sn	119.0	2 or 4	
Zinc	Zn	65.37	2	0.0003387